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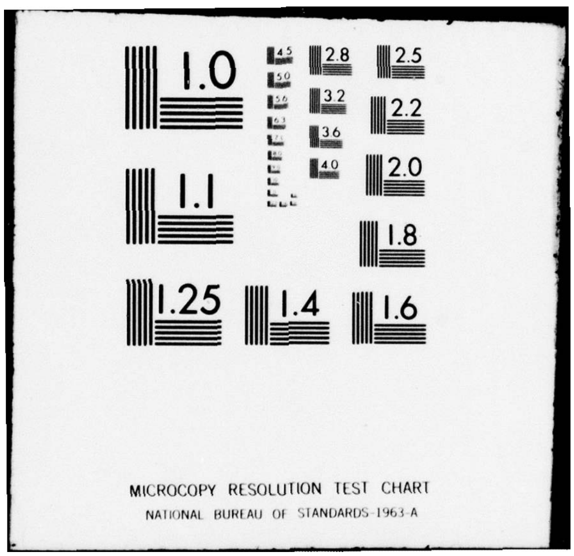
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TECHNICAL REPORT M-78-2

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MOVEMENT OF SUSPENDED PARTICLES AND SOLUTE CONCENTRATIONS WITH INFLOW AND TIDAL ACTION.

by

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Landsat (formerly called ERTS-1) data recorded on computer-compatible tapes (CCT's) augmented by data derived from ground control measurements were used to determine the feasibility of detecting alterations to the optical properties of water caused by the movement of suspended particles and solutes in selected portions of the Chesapeake Bay area.

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Techniques were developed to process CCT's on a PDP-15 computer, establish correlations of radiance and suspended material concentrations, and produce suspended material distribution photomaps. This report discusses these techniques, and includes in appendixes a discussion of experience with automated data collection systems in connection with this study, validation of the computer algorithms for high suspended material concentrations, and by-products that resulted from this study.

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PREFACE

The study reported herein was conducted by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) from July 1972 through May 1974. The study was authorized by NASA Defense Purchase Request No. S-70259-AG dated 19 June 1972, "ERTS - Movement of Suspended Particle and Solute Concentrations with Inflow and Tidal Action," under appropriation 80X0108 433-641-14-04-11 (72), sponsored by the National Aeronautics and Space Administration. Publication of the report was funded by the Office, Chief of Engineers, RDTE Project/Task No. 4A762719-AT40, Work Unit 031, "Mobility/Terrain Data Acquisition Methods," since the information resulting from this study is directly applicable to the Work Unit objectives.

The study was conducted under the general supervision of Messrs. W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory (MESL), and W. E. Grabau, former Chief, Environmental Systems Division (ESD), and now Special Assistant, MESL. Mr. R. R. Friesz, former Chief, Environmental Characterizations Branch (ESB), directed the study with the assistance of Mr. A. N. Williamson, formerly in the ESB and now assigned to the Data Handling Branch (DHB), Mobility Systems Division (MSD), MESL. The data analysis and information portrayal techniques were developed and the report was prepared by Mr. Williamson.

Acknowledgement is made to Mr. J. L. Smith, Chief, DHB, who developed the computer programs required to accomplish the objectives of this study. Acknowledgement is also made to personnel of the Norfolk District, Corps of Engineers (CE); Chesapeake Biological Laboratory, University of Maryland; National Marine Fisheries Service; Chesapeake Bay Institute of Johns Hopkins University; and the Philadelphia District, CE, who provided assistance in gathering ground control data.

Directors of the WES during this study and preparation and publication of the report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	0.0254	metres
miles (U. S. statute)	1.609344	kilometres
square miles	1.609344	kilometres
acres	4046.856	square metres
Fahrenheit degrees	0.555	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin readings, use: $K = (5/9)(F - 32) + 273.15$.

MOVEMENT OF SUSPENDED PARTICLES AND SOLUTE CONCENTRATIONS WITH INFLOW AND TIDAL ACTION

PART I: INTRODUCTION

Background

1. The distribution of waterborne suspended materials and solutes is a hydrodynamic function of a water body. Flow patterns, current velocities, and many other factors can affect the amount of foreign materials carried and the occurrence of erosion or deposition. In most cases, the amount of suspended particles carried by a body of water is determined by the velocity of current flow, the density and viscosity of the water, and size, shape, and specific gravity of the particles. The characteristics of the water depend on the hydrodynamics of the environment, whereas particle characteristics depend on sources of supply and distances over which the particles have been transported.

2. One of the most complex hydrodynamic systems in the United States is the Chesapeake Bay area. Fresh water from a number of rivers flows into the estuary laden with sediments, solutes, and millions of tons of waste and sewage discharged by industries and municipalities. Upon entering the estuary, the inflow is subjected to the environment of the estuary. Tides, salt water, and other factors foreign to the fresh water environment alter the flow patterns and particle distributions. The result is a complex mixing of fresh and salt water and of particle-laden and relatively unturbid waters. Tides change the direction of flow in the estuary daily, and the inflow from the rivers changes seasonally in turbidity, chemistry, and quantity.

3. Characterization of the hydrodynamics of an estuary by on-the-surface teams measuring the various parameters of significance is very difficult; especially on one as large as Chesapeake Bay. The basic reason for this is the physical impossibility of obtaining measurements at a sufficiently large number of points to define the conditions at a given instant in time. To achieve this for an estuary as large as

Chesapeake Bay would require thousands of boats, each identically equipped and so tightly coordinated that the samples or measurements would be taken within a time interval of at most a few minutes. The short time interval is essential because estuarine conditions change rapidly. Measurements spread over any substantital period of time, such as several hours, inevitably result in a badly distorted picture of what might be called the instantaneous condition. Even conventional air photography suffers from the same problem; it takes too long for the aircraft to fly over the entire bay.

4. A second problem revolves around the fact that all ground-based measurements are effectively point samples; that is, they measure conditions at a single point in space. This being so, it is impossible to determine, on the basis of the measured data, whether the sample records a general condition or a chance local anomaly. This makes very difficult, and often impossible, the accurate reconstruction of large-scale phenomena. Thus, because of sampling inaccuracies, the dynamic nature of the estuary, and the inability to obtain an overall view, general trends are often masked by local irregularities.

5. The Baltimore District, Corps of Engineers, is currently undertaking a comprehensive study of the Chesapeake Bay area. The specific objective of this study is to collect and use social, economic, and environmental data relating to the water and land resources of the area in an effort to formulate a sound water-land resources development plan oriented toward both near-future and long-range regional requirements. The study involves a large amount of data gathering on the hydrologic, hydraulic, and water-quality characteristics of the Chesapeake Bay area. The data will be collected for the most part on the ground or in the water. A hydraulic model of the bay area will then be constructed and used to study the hydrodynamics of the region. These studies will require a knowledge of the suspended particle and solute distributions of the Bay.

6. The Earth Resources Technology Satellite (ERTS-1*) of the

* On January 13, 1975, the name of the first Earth Resources Technology Satellite was officially changed to Landsat-1.

National Aeronautics and Space Administration (NASA) offers the potential for monitoring hydrodynamic processes over a period of time. The synoptic view provided by the satellite is ideal for studying phenomena such as suspended material distribution. The conditions existing in an entire 10,000-square-mile* area can be essentially frozen for an instant in time (approximately 27 sec are required to cover an area this size). The ERTS-1 18-day cycle provides coverage that should show changes occurring with time. The multispectral sensing capability of the multispectral scanner (MSS) should detect changes in the spectral reflectance that result from changes in the concentrations of suspended material in the water.

7. In view of this, ERTS-1 with its MSS provides the potential for delineating flow patterns, flushing actions of the estuary, and suspended material dispersion within the Chesapeake Bay study area. This information would be valuable for future design work in the Bay area, evaluation of the area for navigation, pollution control, and other related activities. The ability to discern hydrodynamic characteristics on a regional scale would be of great value to the Baltimore District in its Chesapeake Bay study.

Purpose

8. The primary purpose of this study was to determine the practicability of detecting from the MSS data any alterations to the optical properties of water caused by the movement of suspended materials in selected portions of the Chesapeake Bay area and to determine whether:

a. Variations in suspended material concentrations can be detected, and if so, whether it is practical to obtain quantitative estimates of sediment concentration.

b. Water masses with different types of suspended materials can be differentiated.

c. Water masses can be followed at least through partial mixing.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 8.

d. The interpretations listed above can be achieved using the MSS data and completely automated analytical procedures.

Scope

9. The study was restricted to four areas in the Chesapeake Bay and one area encompassing small portions of both Chesapeake and Delaware bays (Figure 1). The five areas totalled about 3000 km^2.

10. Ground data were collected manually in each area on 10 and 28 October 1972, and 14 May 1973. Also on 10 and 28 October, ground control data were collected with automatic data collection systems at two stations in the study area. However, the satellite sensor data taken on these dates showed the study areas to be entirely visible only on 10 October 1972. As a result, the effects of movement of suspended materials on the optical properties of water could not be determined.

11. Satellite sensor data were restricted to MSS computer compatible tapes (CCT's). Development of analytical techniques and related computer programs to process the CCT's was restricted to that required to determine and map the distributions of suspended material concentrations and to differentiate among those types of materials found in the study areas. No attempt was made in the basic study to extrapolate the results to other regions or conditions.

12. The main body of this report presents the results of the study using the 10 October 1972 ERTS-1 MSS data and ground control data. Appendix A presents experience with the automatic data collection system. Appendix B contains the results of supplemental studies to validate the data processing algorithms for high concentrations of suspended material. Appendix C discusses by-products (i.e. the capability to inventory water bodies and to produce flood maps) that have resulted from this study.

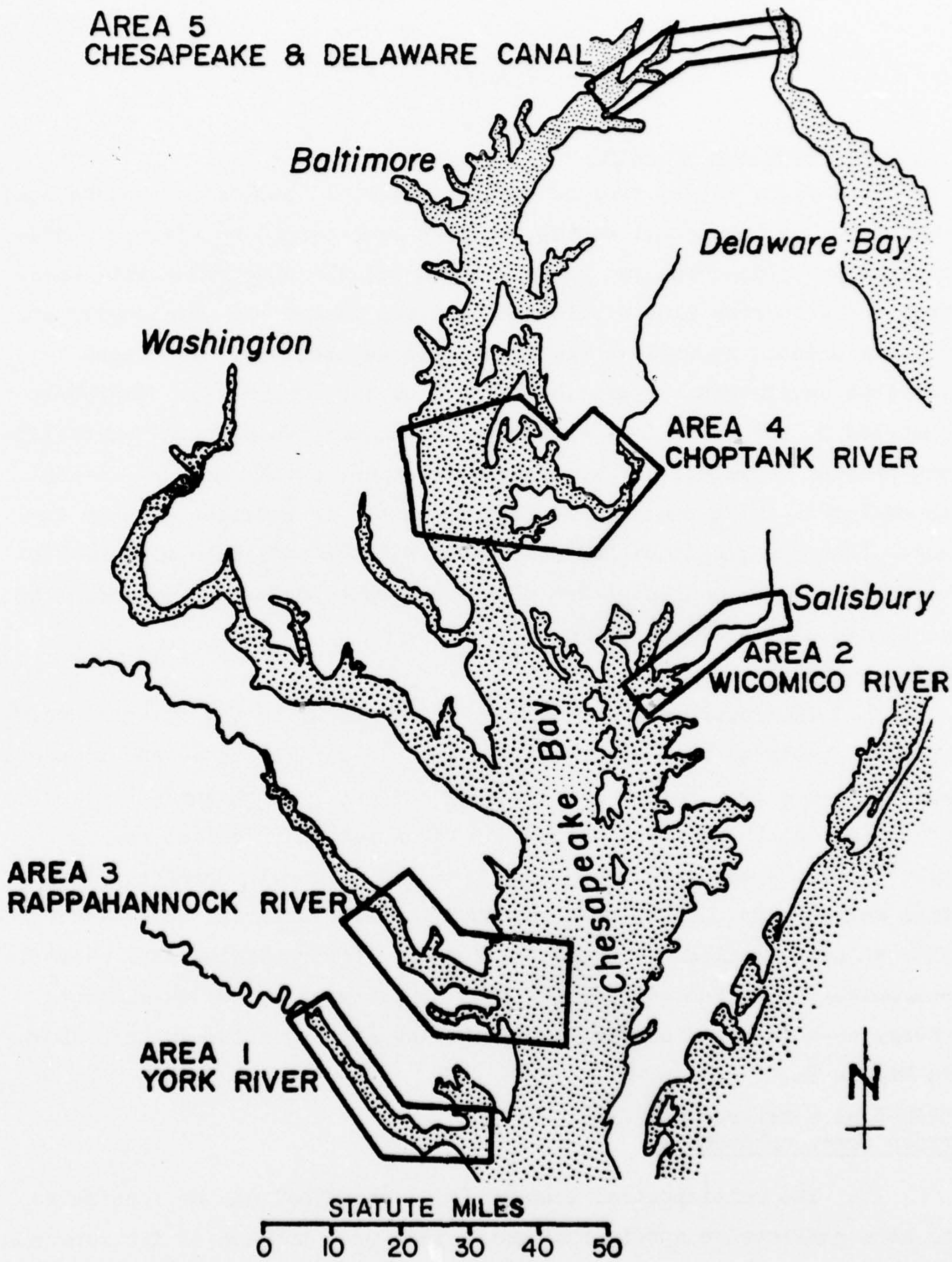

Figure 1. Chesapeake Bay study areas

PART II: PLAN OF RESEARCH

Rationale

Optical properties of water

13. Clear water, free of foreign materials such as suspended sediment loads or industrial wastes, is most transparent to visible radiation in the blue-green and green portions of the electromagnetic spectrum. The shorter blue wavelengths and the longer red wavelengths are not transmitted as well as the blue-green wavelengths. The near-infrared wavelengths (approximately 0.8 μm and longer) are completely absorbed by the first few centimetres of water. When foreign materials are present in water, the spectral reflectance of the mixture varies depending on the types of materials present. In addition, theory suggests that the amount of radiation that will be reflected will be proportional to the concentration of the suspended material, provided the suspended particles are reflective.[1]

Reflectance spectrophotometer

14. The instrument commonly used for measuring the spectral reflectance of water as well as other materials is a reflectance spectrophotometer (Figure 2). In its basic configuration, it contains (a) a source of radiation, (b) a prism or grating for separating radiant energy reflected from a material under test into its spectral components (spectral reflectance), (c) a detector that converts spectral reflectance into an electrical analog, and (d) a device for recording that electrical output. The recording gives the intensity of reflected radiant energy as a function of wavelength and may appear as the example shown in Figure 3a.

ERTS-1 as a reflectance spectrophotometer

15. The multispectral scanner (MSS) on ERTS-1 can be considered to be a reflectance spectrophotometer that uses the sun as its source of radiation, and is configured to measure the spectral reflectance from the earth's surface. In place of a prism or grating, filters are

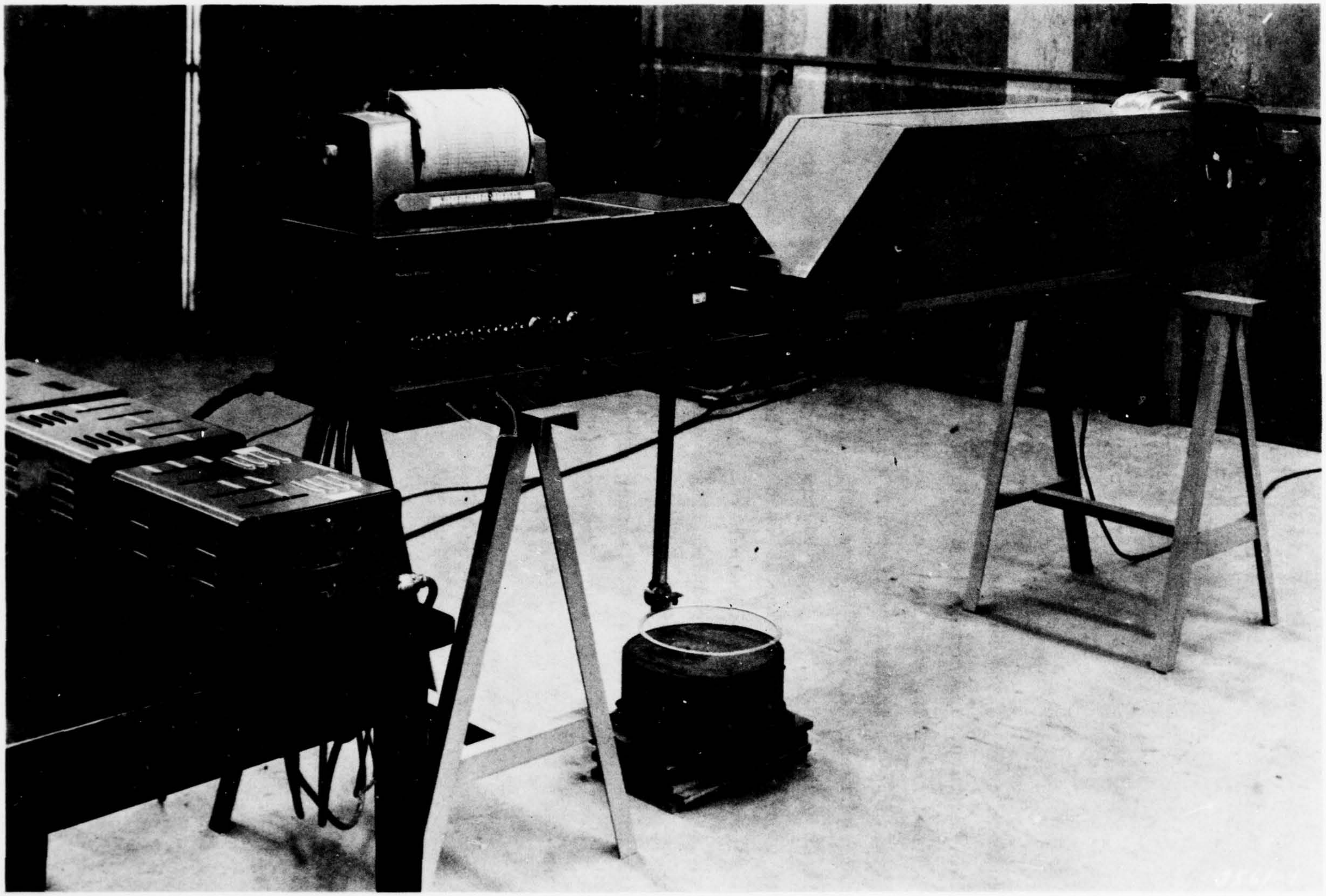

Figure 2. Reflectance spectrophotometer

used to separate the radiant energy reaching the satellite into four spectral bands as follows:

Band No.	Wavelength μm	Approximate Color
4	0.5-0.6	Green, yellow, orange
5	0.6-0.7	Red
6	0.7-0.8	Red and near-infrared
7	0.8-1.1	Near-infrared

Detectors convert the radiance energy in each band to electrical analogs, which, in turn, are converted to digital form, transmitted via telemetry to ground receiving stations, and recorded on computer-compatible tapes (CCT's). Thus, unlike the spectrum derived from a laboratory reflectance spectrophotometer (Figure 3a), a spectrum derived from the MSS will actually be a histogram (Figure 3b) that shows the average intensity of reflected radiation in each of the four MSS wavelength bands.

16. Users of ERTS-1 data have a choice of either the CCT's for a scene or a set of NASA-produced images derived by exposing a photographic film to a lamp or a cathode ray tube that is intensity-modulated an amount proportional to the amount of radiant energy detected by the MSS. The U. S. Army Engineer Waterways Experiment Station (WES) chose to use only the CCT's for two principal reasons:

a. An objective was to develop completely automated procedures for interpreting the data in terms of suspended material concentration and type. Considering the massive amount of numerical data represented by one ERTS-1 scene, this objective implied the use of computer processing. Since the computer selected for use required magnetic tape input, it seemed logical to begin the process with an existing tape.

b. More important is the fact that the data on the CCT's represents primary data; whereas, the NASA-produced images are a secondary product in which the process of reproduction has resulted in a considerable degradation of the primary data. Since it was virtually certain that the recognition of variations in suspended material concentrations would require the identification of quite small variations in radiance in the various spectral bands, there seemed little choice but to use the CCT's directly.

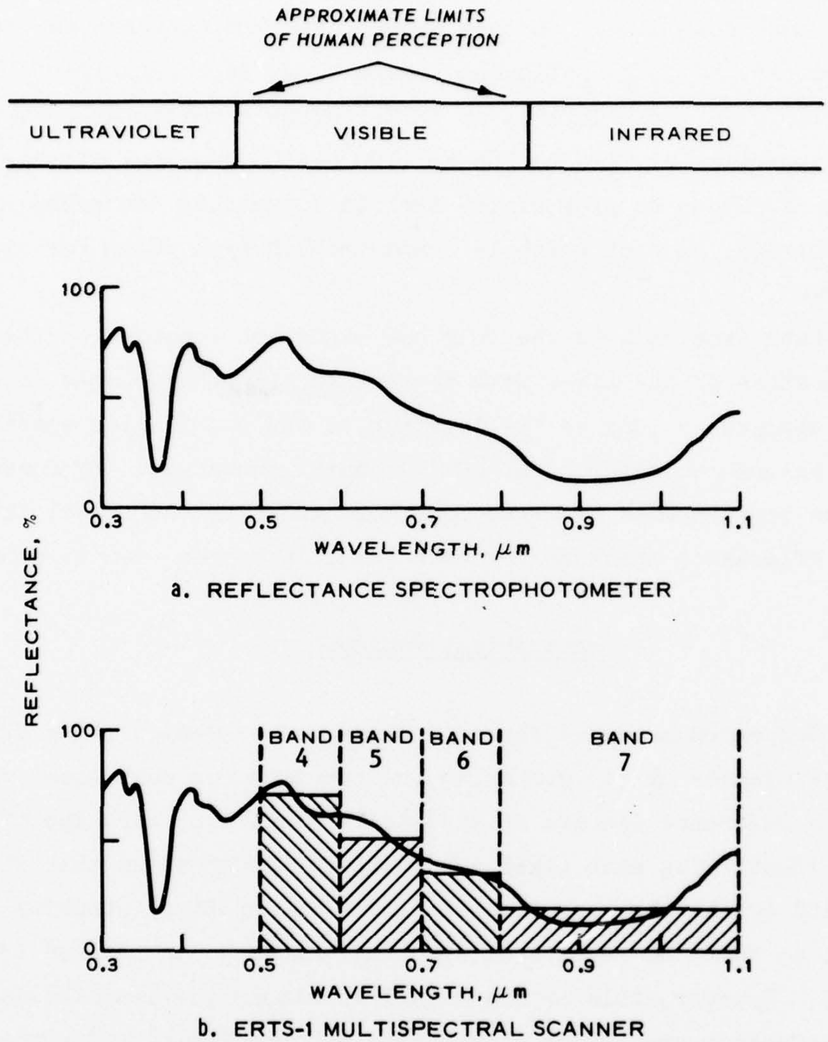

Figure 3. Water spectrum as defined by a reflectance spectrophotometer and the ERTS-1 multispectral scanner

17. The information recorded on the CCT's can be described best by considering the measurement sequence of the MSS. The following is a simplification of the actual measurement sequence. The MSS has an instantaneous field of view that encompasses a spot on the terrain surface (picture element or pixel) about 57 by 79 m in size (approximately 0.45 ha) at the nadir point. A scanning mirror causes the instantaneous field of view to be deflected along lines normal to the orbital path of

the satellite while successive measurements are made at regular intervals along each scan line. In this manner, the MSS measures the spectral reflectance of 3240 contiguous pixels along each scan line. A total of 2340 scan lines defines an ERTS-1 scene covering an area on the ground of approximately 185 by 185 km (100 by 100 nautical miles).[2,3] Thus, each 34,225-sq km area of the terrain surface is described by 7,581,600 pixels, each of which is characterized by a value for each spectral band.

18. Data from each of the four MSS bands are recorded on the CCT's, and the location of the pixel with respect to all other pixels in a scene is retained as long as the location of the pixel value within a series of values recorded on the CCT's remains unchanged. By consolidating the measurements from the four MSS bands for each pixel in a scene, a reflectance spectrum for each pixel in a scene can be obtained.

Analytical Concept

19. Suspended material concentrations can be mapped using ERTS-1 reflectance spectra by (a) comparing the spectrum for each pixel with one or more reference spectra related to type and concentration of material; (b) identifying each pixel according to the spectrum that it matches; and (c) at the same time retaining the spatial integrity of each pixel so that the results of spectrum matching can be used to generate maps. However, this approach implies either the availability of suitable reference spectra or a technique for predicting reference spectra.

20. Reflectance spectra for water containing various materials in suspension have been measured under controlled laboratory conditions and by carefully executed field procedures. However, these spectra pertain to water conditions and in many cases to the spectral characteristics of the source of illumination only at the time the measurements were taken. As a result, these spectra are of little value for mapping suspended material concentrations because they do not represent the irradiance conditions at the time of the ERTS-1 overpass.

21. Prediction models suitable for defining the spectral characteristics of different objects or materials are being developed, but at this point are not adequate for extensive use in remote sensor data interpretation. One such model developed at WES has been used to determine the optimum film-filter combination for detecting a target whose spectral reflectance characteristics are known. In addition, the model computes the proper F-stop and shutter speed required to make the target appear on the film with a specified contrast ratio against its background or surroundings.[4] This same model can be used to compute the spectral signature of any target as it would appear to a sensor at specified altitude and atmospheric conditions, provided the scattering and absorption properties of the target are known.

22. Another model of potential value for predicting spectral signatures of suspended materials is being developed at Colorado State University.[5] This model computes the apparent directional reflectance of vegetation on the basis of solar angle and view angle, canopy geometry and optical properties, and soil background.

23. A model for the express purpose of predicting the way the reflectance spectrum of a water body containing specified constituents would appear to the ERTS-1 MSS on a specified orbit has not been developed. Suspended material concentrations will apply only to the ERTS-1 scene under investigation, and because of changing material type and concentration, sea state, sun angle, and atmospheric condition, will have little, if any, bearing on interpretation of data derived from other orbital passes over an area.

24. The "ideal" plan of research for this study (Figure 4) was designed to result in the capability to predict the spectral reflectance for various suspended material concentrations, as seen by the ERTS-1, for any set of atmospheric and sea-state conditions. The product, by application of automatic data processing techniques, was intended to be maps of suspended material distributions. Two general tasks were to be undertaken:

- a. Development of a mathematical model for the spectral reflectance from an area on the basis of alterations to

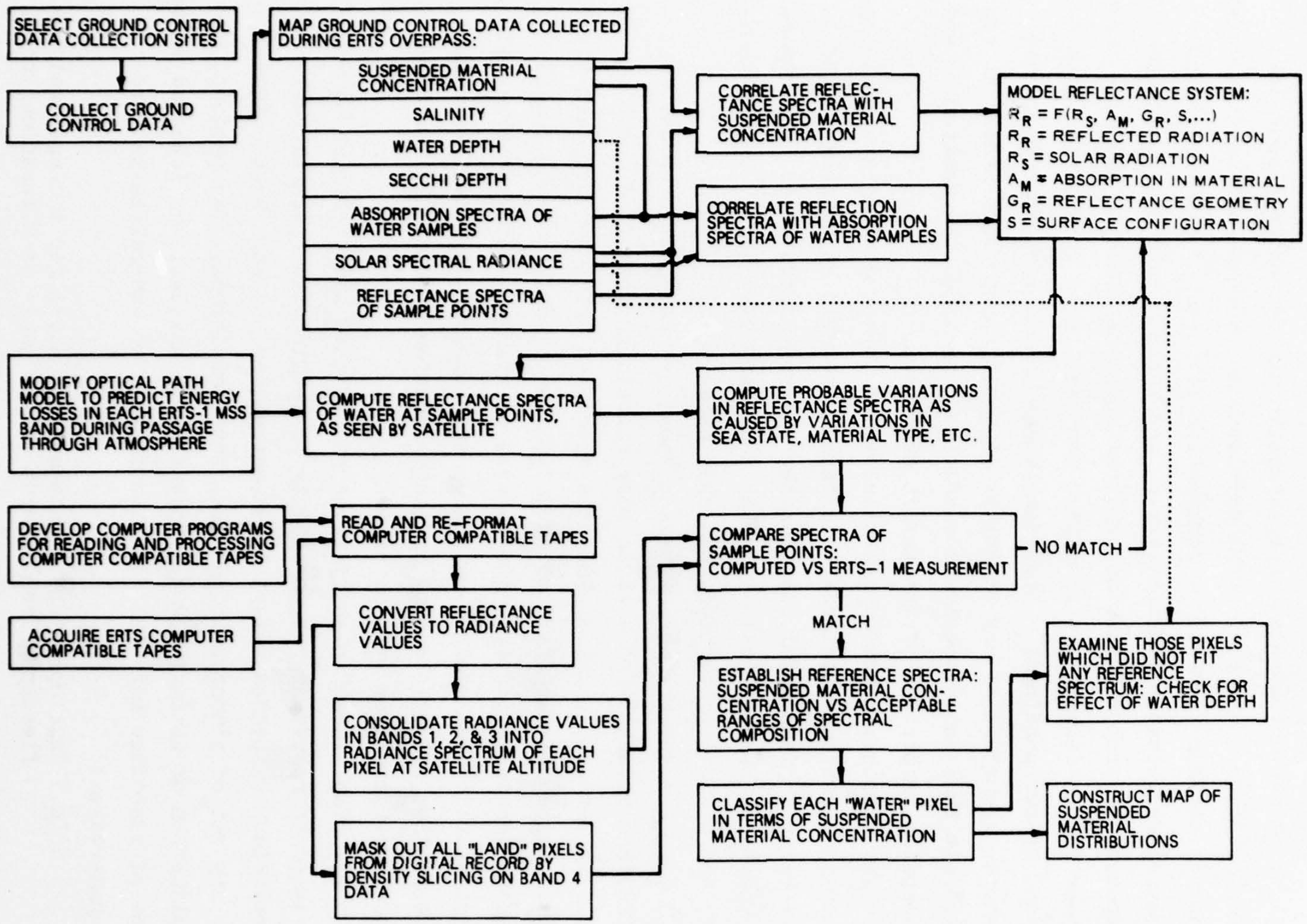

Figure 4. "Ideal" research plan

solar spectral irradiance due to time of day (solar altitude), time of the year, the latitude of the ERTS-1 scene in question, weather conditions, the amount of scattering by dust particles and aerosols, absorption by atmospheric gases, the inclination of the surface with respect to the sun's rays (e.g. surface roughness), and absorption and scattering caused by materials in the water.

b. Development of the capability to read and process CCT's to obtain the reflectance spectra for pixels in an ERTS-1 scene and apply the results to produce maps of suspended material concentrations.

25. It was envisioned that the model would be formulated and then tested with ground control data taken within the same time period as the ERTS-1 overpass. The ground data would be used to establish the correlation of spectral reflectance and suspended material concentration and the correlation of spectral reflectance and spectral absorption (Figure 4). A reflectance system model would then be formulated to predict the spectra of reflected energy that could be measured at ground (water) level for different suspended material types and concentrations.

26. The output of the model would then be corrected for losses that occur in each MSS band during passage of the reflected energy through the atmosphere to ERTS-1. This would be accomplished by application of an atmospheric transmittance model described in reference 6. The resulting spectra would then be compared with spectra derived from MSS data for the points on the water where ground control data had been taken. If a match occurs, the results could be used to generate maps showing the distribution of suspended material concentrations in a study area.

Research Plan

27. Early in the study, the rapidly mounting costs of obtaining adequate ground control data made necessary the revision of the basic research plan. The concept for the revised plan is based on the premise that a given material near the surface of water will always yield the same reflectance spectrum as viewed by the satellite, provided certain conditions are met. These conditions are as follows:

a. The constituents of the material are constant. For example, if the material is a soil-water mixture, a match with a given spectrum will not occur if the ratio between soil and water changes.

b. The surface expression of a material remains unchanged. For example, if the material is water, it would not be expected to look the same spectrally under substantially different wave conditions.

c. The reflectance geometry is similar. For example, a significant change of sun angle would affect the reflectance spectrum.

d. The atmospheric composition is the same. Significant changes of absorption and scattering occur as a result of changes in aerosol content of the atmosphere, and thus a change in type or density of haze will change the spectral composition of radiation reaching the satellite.

28. If the above conditions are met, then it follows that the spectral data, as sensed by the satellite, could be correlated directly with conditions in the water. This means that a specific type and concentration of suspended material would be represented by the same spectrum throughout any one ERTS-1 scene, since all four of the conditions specified above (with the possible exception of condition b) would be met. Condition b, identity of surface expression, might not be met, since wave conditions are unlikely to be the same throughout an entire estuary. As a result, exact spectra matches cannot be expected. However, if acceptable limits of variation can be established, conversion of reflectance spectra (as measured by the satellite) into concentration of suspended material on a pixel-by-pixel basis throughout an ERTS-1 scene may be possible. The result would be a map of the distribution of suspended material, by concentration classes, produced by a completely automated process.

29. This procedure does, however, have inherent inadequacies. By far the most important of these is that little, if any, predictive capability will result. Therefore, correlations used to map suspended material concentrations will not be applicable to the scene obtained on the next orbital pass, because all four of the previously specified conditions may be different. That is, the type of sediment may be somewhat different, the sea state may be different, the sun angle may be

different, and the atmospheric composition may be different. In view of the number of possible variables, it is unlikely that the same correlations will be valid for any extended period.

30. A flow diagram of the research plan that was actually followed is shown in Figure 5. The plan identifies five basic items of work to be accomplished to achieve the objectives of this study. These are as follows:

- a. Select ground control data collection sites and collect data at these sites on water characteristics, factors that influence water surface characteristics, and atmospheric transmittance of radiation in the four MSS bands between 0.5 and 1.1 μm.
- b. Develop the capability to read and process CCT's. This involves development of computer programs that will accept the values recorded on CCT's as input, convert these values to radiance (in mW/cm^2-sr), and assemble the values to define the reflectance spectrum for each pixel. The ability to convert CCT values to radiance and then make corrections for atmospheric effects is desirable so that measurements from the MSS can be compared with similar measurements at ground (water) level. Unfortunately, no spectral reflectance measuring instruments were available for this study.
- c. Correlate suspended material concentrations at each ground data collection site with the reflectance spectrum for that location. Each reflectance spectrum would be derived from a computer printout of the band-4, -5, and -6 radiance values. Thus, in this step a computer program would be developed to print out the radiance values in a form that would permit locating the values corresponding to each ground control data collection station. The results would be a set of reference spectra correlating specific suspended material concentrations with specific reflectance spectra.
- d. Develop a technique for matching each water pixel reflectance spectrum with a corresponding reference spectrum, thereby identifying the water pixel according to the suspended material concentration represented by the reference spectrum.
- e. Develop a method for generating maps that show the distribution of material concentrations in selected test areas.

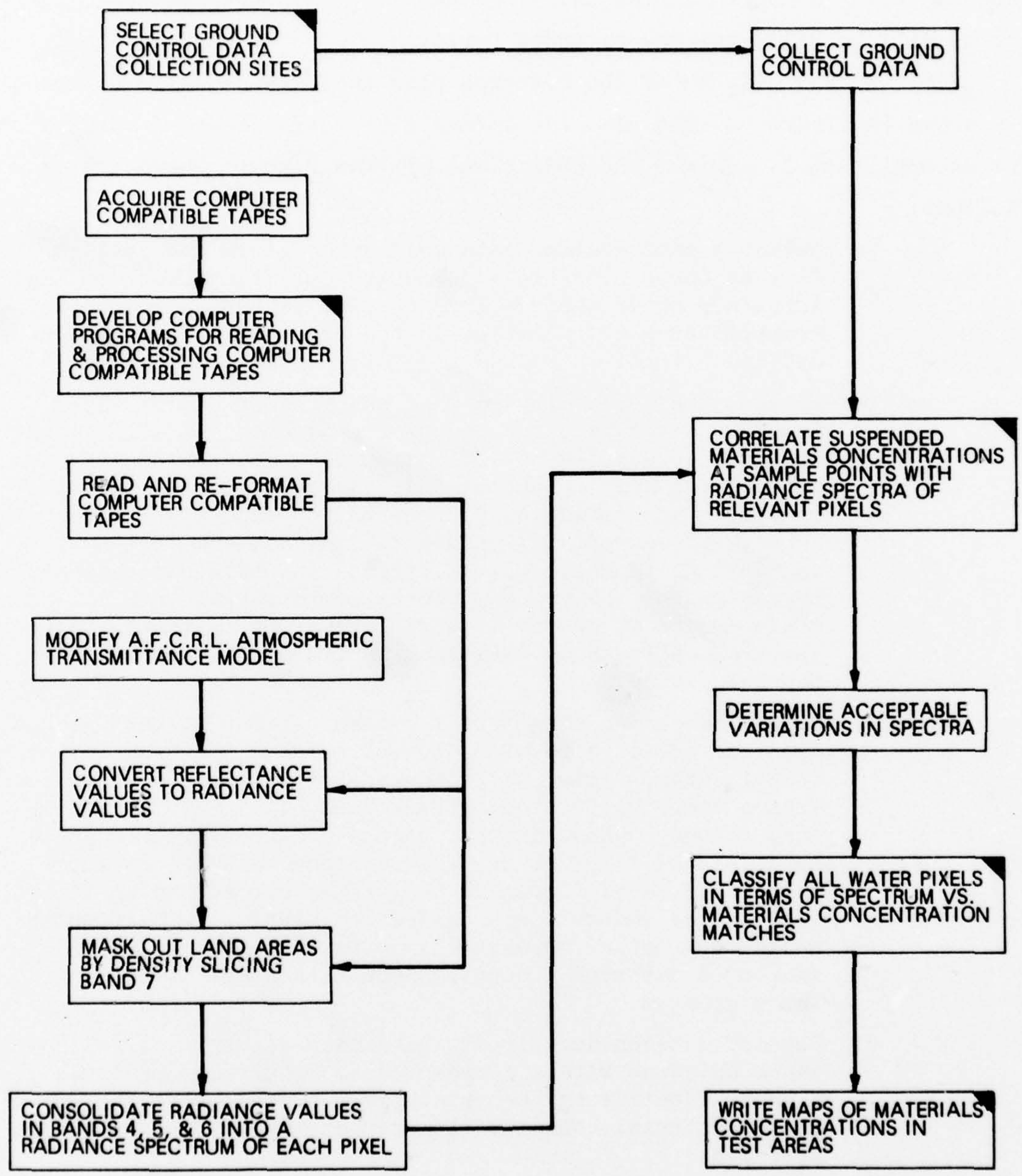

Figure 5. Flow diagram of research plan followed

PART III: GROUND CONTROL DATA COLLECTION

Study Areas

Selection criteria

31. This study was centered on Chesapeake Bay because of the intense Federal, State, and local concern over the condition of the Bay. However, to keep the scope of this study within reasonable limits, the specific areas to be included in the study were limited in number. The criteria for selecting the study areas were as follows:

- a. Each area should include a reach of river, discharging into Chesapeake Bay, that would be broad enough to accommodate a relatively large number of ERTS-1 pixels, so that at least some of the pixels would unequivocably represent only open-water surfaces.
- b. Each area should be characterized by a unique suspended material type, so that each would have a reasonable likelihood of exhibiting a unique spectral "signature."
- c. Each area should include a portion of the open Bay large enough so that the dispersion of the suspended material "plume" could be examined.

32. Since little or no spectral data were available on the waters of rivers discharging into the Bay, it was clear that criterion b above could not be met directly. In view of this, criteria were formulated as alternatives to b.

- a. It was assumed that, since the suspended materials in the river waters would be derived largely from the soils of the various drainage basins, the criteria would be approximated by selecting rivers draining basins each characterized by unique combinations of soil types.
- b. It was also assumed that the effluents of fundamentally different types of industries would exhibit different spectral characteristics, and thus each river would be characterized by a unique form of industrial development.

33. After careful consideration, portions of the York, Wicomico, Rappahannock, and Choptank Rivers and the Chesapeake and Delaware (C&D) Canal were selected (Figure 1). Portions of Chesapeake Bay adjoining the Rappahannock and Choptank Rivers and a portion of the Elk River and

of Delaware Bay adjoining the C&D Canal were included in the areas to be considered.

34. The C&D Canal was included as a study area for two primary reasons:

a. To determine if the water masses that passed through the canal could be detected in the two bays.

b. To determine if a water feature as narrow as the C&D Canal would yield reliable spectral information in the ERTS-1 data. The critical factor in this consideration is pixel size; the canal is approximately 180 m wide, and an ERTS-1 pixel is about 79 m long. Thus, at best the canal is only about 2.3 pixels wide. In consequence, much of the canal will be represented in ERTS-1 data by a line only one pixel wide. The question is whether the radiation scattered from the adjacent land will "contaminate" the radiance values of water pixels to such a degree that the water pixels cannot be interpreted in terms of suspended material concentration.

York River and Wicomico River (Areas 1 and 2 in Figure 1)

35. The York and Wicomico Rivers were selected primarily because each has a large industrial concentration near the upper limit of the tidewaters, and thus would yield data for studying the feasibility of using ERTS-1 data to monitor the dumping of industrial wastes into tidal rivers. The focal points are a paper mill near West Point, Virginia, where industrial waste is dumped into the York River, and a poultry processing plant in Salisbury, Maryland, where primarily organic waste is dumped into the Wicomico River.

36. These sites provide reasonably clear-cut examples of industrial wastes discharged into an estuary. In both cases, the waste is derived chiefly from a single industrial type, so that the nature of the waste-waters could be readily established. In addition, the material is discharged into a comparatively small estuarine channel so that adequate ground control data could be obtained with a small number of sampling points.

37. The drainage basin of the York River includes large sections of the Piedmont and Coastal Plain Provinces, both of which are under relatively intensive cultivation, and would thus be expected to carry

large suspended material loads, especially during the spring and early summer. A major soil component is the reddish, sandy Cahaba Series. The drainage basin does not extend to the slopes of the Blue Ridge Province.

38. The Wicomico River drains a portion of the south-central Delmarva Peninsula. Some of the area is under cultivation, but land slopes are very gentle, and thus the suspended material loads would not be expected to be very high, even during the spring runoff period in March and April.

Rappahannock River (Area 3)

39. The drainage basin of the Rappahannock River includes the eastern slopes of the Blue Ridge Province, the entire width of the Piedmont, and a narrow slice of the Coastal Plain.

40. The Rappahannock River drainage basin lies within the State of Virginia, beginning in the northeast mountain area and running southeast for about 208 km until it discharges into Chesapeake Bay. The basin is T-shaped, being 91 km wide at the headwaters and about 19 km wide near the mouth. The watershed area is about 6990 sq km, or approximately 7 percent of the area of Virginia.

41. The headwaters of the drainage basin begin in the Blue Ridge Province, where elevations are 1200 m above mean sea level. The highest reach of the streams in the basin have a gradient of 94.5 m/km for the first 3 to 5 km and 9.5 m/km for the next 10 km. In these reaches of the drainage basin, the channels are V-shaped and straight, and have very little floodplain from which sediments can originate. In the Piedmont Province, the river flows in a sinuous channel with limited floodplains. This reach of the Rappahannock River basin is subject to very severe floods. The soils of the area are dominantly brown and dark brown. The River lies in the Coastal Plain Province for about 61 km below Fredericksburg, and meanders through a wide floodplain made up of huge swamps and marshes. From this point to the mouth of the river, about 80.5 km, the Rappahannock is a typical estuary averaging about 3-km wide, but reaching about 6 km in width at the mouth.

42. The average freshwater discharge at the mouth of the

Rappahannock River is about 110 m^3/sec and the observed maximum discharge was 4389 m^3/sec in October 1942. The average depth is about 4.5 m. The average mean tide range at the mouth is 0.5 m and about 0.6 m at the northwest edge of the study area in the vicinity of Tarpley Point. The average flood and ebb tidal current magnitudes are about 0.52 m/sec for the largest part of the estuary. The tidal phase and ranges and tidal currents are greatly influenced by wind conditions.

43. Maximum suspended material transport in the surface water of the Rappahannock River can be expected to occur during the early spring runoff periods, during late February and all of March. The maximum concentrations during this period can be as much as 100 mg/ℓ for several days. However, during the remainder of the year, the average can be expected to be about 5 to 7 mg/ℓ, except during periods immediately following very intense rainfall. The suspended materials will probably be derived mostly from the Piedmont agricultural areas.

44. The distribution of bottom sediment shown in Figure 6 is an interpretation based on descriptions of sediments collected during nine traverses of the estuary.[7] Sand is most abundant along the edges and over a wide area near the mouth. Silt in the deep channel gives way to clay with increasing distance from the mouth.

Choptank River (Area 4)

45. The drainage basin of the Choptank estuary includes much of the north and central Delmarva Peninsula. The basin begins in the State of Delaware and runs southwest for about 80 km until it reaches Chesapeake Bay. The basin is S-shaped with an average width of about 24 km. The watershed area is about 2150 sq km. The drainage basin is in a coastal zone of Chesapeake Bay with the headwaters beginning at an elevation of less than 30 m, and much of the area is lower than 6 m. A large portion of the Choptank River drainage basin is in the estuary zone of the Choptank River.

46. The average freshwater discharge at the mouth of the Choptank River is about 28 m^3/sec and the maximum observed discharge was about 198 m^3/sec on 4 August 1967. The average depth is about 3.7 m. The average tide range at the mouth is about 0.5 m and increases to about

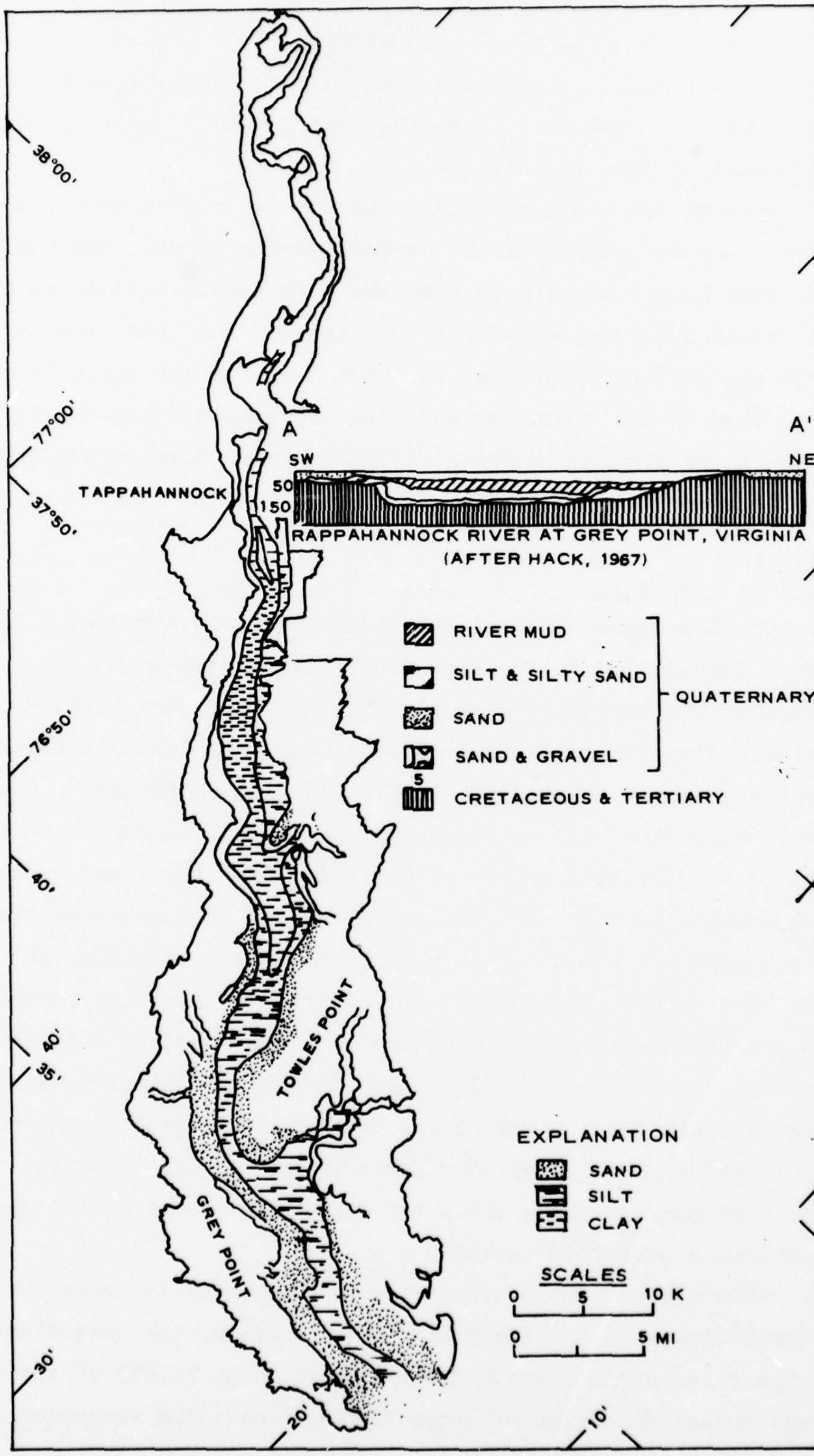

Figure 6. Distribution of bottom sediments in the Rappahannock River

0.6 m near the head of the tide. The average flood and ebb tidal current velocities are about 0.3 m/sec. As in the Rappahannock River (paragraph 42), the wind greatly changes the tide phases as well as current velocity phases and magnitudes.

47. Maximum suspended material transport in the surface waters can be expected to occur during runoff periods during March. The maximum concentrations during certain days of the high runoff period can be expected to be around 80 mg/ℓ. For the balance of the year, the average concentrations can be expected to be about 5 mg/ℓ. The basin is very similar to that of the Wicomico, and thus the suspended materials would be expected to be similar to those in the Wicomico River above the poultry processing plant.

Chesapeake and Delaware Canal (Area 5)

48. The Chesapeake and Delaware (C&D) Canal is a man-made sea-level canal that begins in the Delaware River estuary at a point about 16 km south of Philadelphia, Pennsylvania, near Delaware City, and runs in a westerly direction for about 29 km across the States of Delaware and Maryland until it intercepts the Elk River, a tributary of Chesapeake Bay. This canal has a mean depth of about 11 m and a bottom width of about 137 m. The side slopes of the canal are very steep. The tidal histories associated with the Delaware River and Chesapeake Bay are very important, because the mean tide levels between the estuaries at opposite ends of the canal can vary greatly in relatively short periods of time and can produce large net eastward or westward discharges (e.g. up to 396 m^3/sec) through the canal. These discharges transfer water between the two estuaries in very large quantities. Since the normal conditions of salinity and other attributes of water quality in the two estuaries vary considerably, the water exchanges caused by the canal have long been a matter of concern.

49. About 95 percent of the suspended material in upper Chesapeake Bay in the vicinity of the Elk River is provided by the Susquehanna River. The river has a maximum discharge of about 22,653 m^3/sec and an average annual discharge of about 1133 m^3/sec. The suspended

material during the spring freshet (March) is a maximum of about 140 mg/ℓ with a yearly average of about 5 mg/ℓ. However, suspended material concentrations exclusive of March in the upper Bay average about 7 mg/ℓ, which is higher than that at the mouth of the Susquehanna. This variation is caused by a resuspension produced by such forces as density currents, wave action, and wind-driven and tidal currents.

50. The major source of suspended materials in Delaware Bay (in the vicinity of the Canal) is the Delaware River, which has an average discharge of about 595 m^3/sec.

Data Collection Stations

51. Ground control data were collected to provide information that could be correlated with data derived from the MSS. The product of such a correlation would be, ideally, a defined relation between the material of interest and its reflectance spectrum. In this case, the objective was to develop a relation between suspended material concentration and the associated reflectance spectra in each of the five study areas, thus defining for each study area what might be called a family of reference spectra.

52. Clearly, the samples and measurements in the ground control data collection program had to be taken with the utmost care to ensure that they would be as truly representative of the conditions of interest as possible. There were two general areas of concern that had to be carefully weighed; namely, the selection of the locations of the data collection stations and the nature of the instruments and devices used to measure the data of interest.

Criteria for selection of data collection stations

53. Of necessity, in the absence of any significant amount of hard data on the relation to be expected between suspended material concentrations in the five study areas and spectral reflectance, the selection of data collection stations in each of the four river estuaries and the C&D Canal was largely subjective. However, a consideration of the

physics of the process of light reflection and of the operating principles of ERTS-1 provided qualitative guidance. The following considerations strongly influenced the station selection process.

54. Timeliness of data. Ideally, all ground control data should be taken at the exact instant in time at which the MSS is measuring the spectral reflectance of the point at which ground control data are taken. However, this was obviously impractical because of the logistic support, instrumentation, and manpower required. The alternative was to select station locations that were easily accessible within a time frame that included the time of satellite overpass. Then only a very limited number of boats, personnel, and instruments would be required. However, in the analysis of the resulting data, consideration would have to be given to changes in conditions existing at a station location between the time the data were taken and the time of the satellite overpass.

55. Water depth. If the radiation being received by the MSS had penetrated the water and reflected off the bottom, it was obvious that the value recorded by the MSS would not necessarily be a characterization of the reflectance of the suspended particles. There may, in fact, be no relation whatever, because there is no reason to assume that the bottom materials would be related in any way to the suspended materials. To minimize the probability that the measured radiation was reflected from the bottom, stations should be selected at locations where the water depth exceeded the expected penetration. This was by no means possible. For example, band-4 wavelengths (0.5 to 0.6 μm) are known to penetrate to depths of more than 20 m.[8] However, such penetration is possible only when the water is free of suspended materials; in the turbid water expected in Chesapeake Bay, the depth was not expected to exceed 5 m, and in most cases it was expected to be less than 2 m.

56. Shadows. Energy detected by the MSS is solar radiation that has propagated along a path through the atmosphere to the earth's surface. At the earth's surface, the energy is reflected and scattered, and some of it is propagated back through the atmosphere to the MSS. Any material or feature that interrupts the propagation causes an alteration to the spectrum of radiant energy that ultimately reaches the MSS.

Obviously, the occurrence of clouds and other transient phenomena that might affect propagation cannot be reliably predicted. Care can be taken, however, to avoid selecting station locations with a high probability of having their MSS-measured reflectance spectrum altered either by shadows, such as might be cast by bridges or other structures, or by secondary scattering, such as by cliffs or trees near the water.

57. Representativeness of specific locations. The water in an active estuary such as Chesapeake Bay is in continual motion under the diverse influences of tides, winds, density currents caused by variations in suspended material concentrations and salinity, changes in water levels in the associated rivers, and wave action. These complex currents control the movement and deposition of suspended materials, and thus the concentration of those materials at any given location or set of locations in the Bay. It is therefore impractical, if indeed even possible, to select with any degree of reliability station locations that can ensure good representation of the range and distribution of suspended materials. In view of this, the stations were (in general) arbitrarily spaced uniformly along the major axis of each river or channel. There were exceptions, however. For example, two sample points in the York River near West Point were located in places where high concentrations of sediments were expected because of special local conditions.

58. Since one objective of the experiment was to determine to what extent the suspended material clouds could be traced during the process of mixing in the open bay, stations were also placed in the bay off the mouths of the rivers and channels. However, since there was little or no information available that would permit the selection of "ideal" characterization sites, the open-bay stations were placed at approximately equal distances along lines where position location was relatively easy (see Figures 7-11).

Stations selected

59. Using the criteria above as guidance, 77 stations were selected. Their distribution in the various study areas is as follows:

Study Area	Figure No.	Number of Locations In River	In Bay
York River	7	14	4
Wicomico River	8	9	2
Rappahannock River	9	13	7
Choptank River	10	11	5
C&D Canal	11	5*	7**

* Sites in Canal.
** Sites in Elk River and Delaware Bay.

Data Collection

Data collected and equipment used

60. The ground control data selected for collection during the ERTS-1 overpass were those that describe water conditions, influence water surface conditions, and describe the spectral characteristics of solar radiation impinging upon and reflecting from the water surface. Suspended material concentration and secchi disk depth and color were considered essential. However, pH, conductivity, water temperature, dissolved oxygen, salinity, current velocity, and water color were also measured for possible use in data interpretation.

61. Suspended material concentration was determined from water samples taken as described in paragraph 67 and tested as described in paragraphs 68 and 69. Other data were collected using equipment described in Table 1.

Method of collecting data at the sites

62. The ground control data were collected by personnel of laboratories and institutions that normally work in the area. The organizations and relevant details are summarized in Table 2. Instrumentation was supplied by the participating organization, but in no case was instrumentation with a full complement of sensors available for measuring all parameters. There are, therefore, significant gaps in data such as conductivity, dissolved oxygen, and, particularly, pH. In addition,

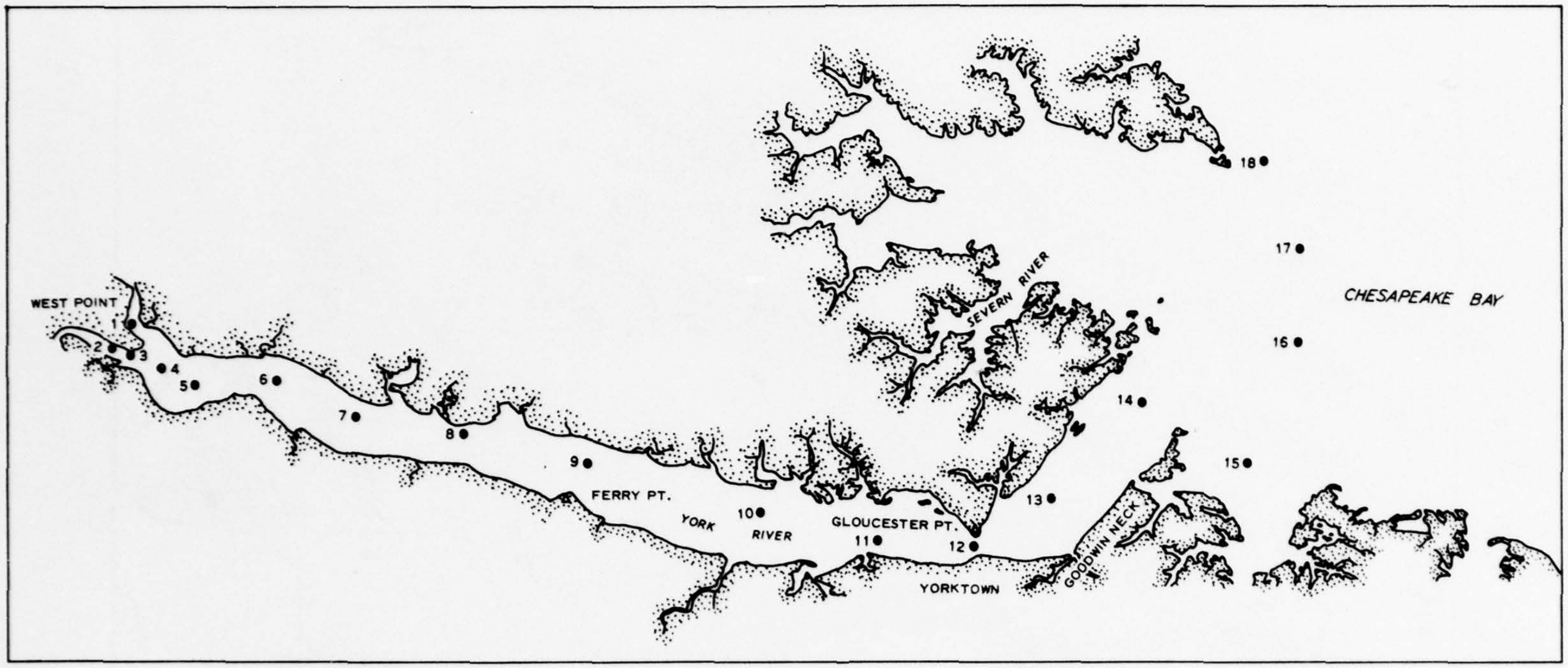

Figure 7. Location of ground control data collection stations, York River and portion of Chesapeake Bay

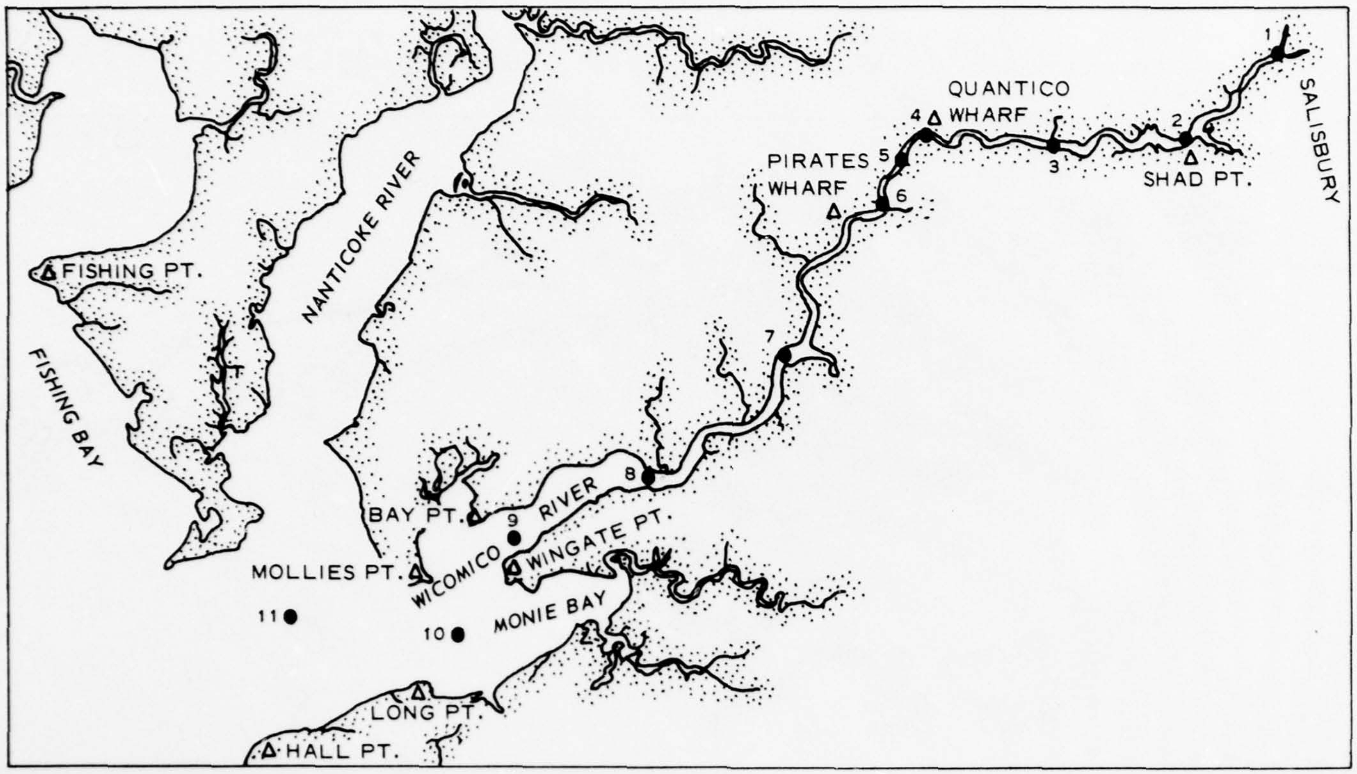

Figure 8. Location of ground control data collection stations, Wicomico River

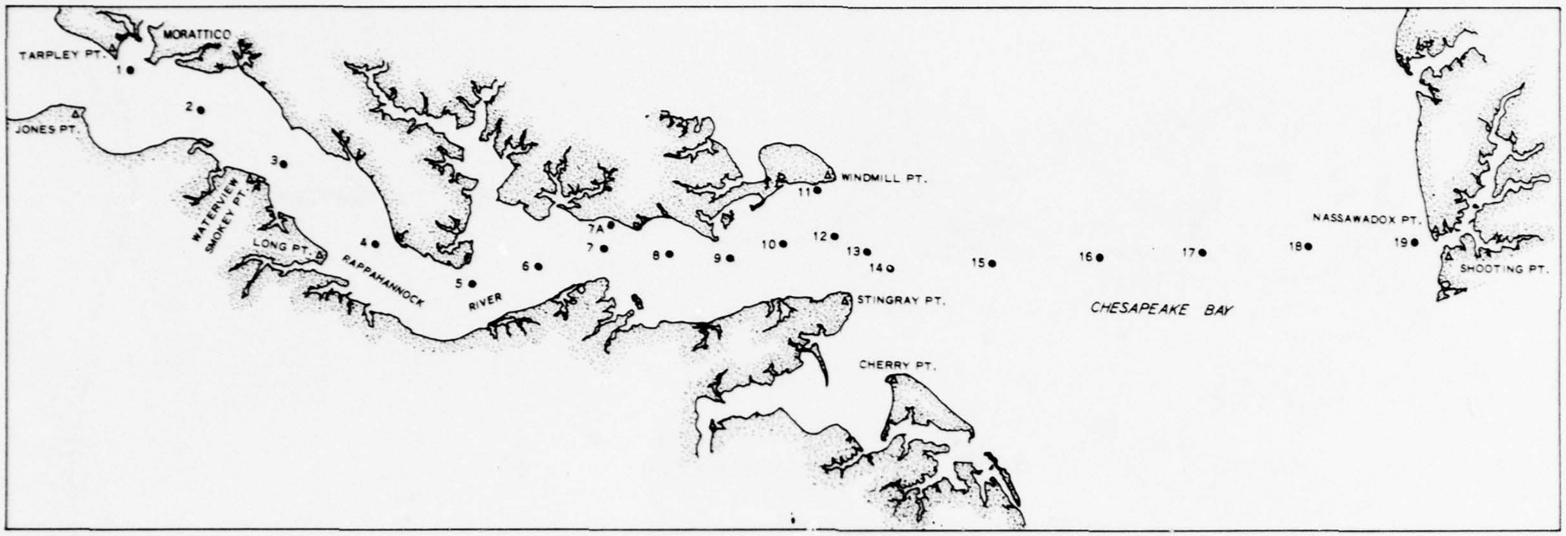

Figure 9. Location of ground control data collection stations, Rappahannock River and portion of Chesapeake Bay

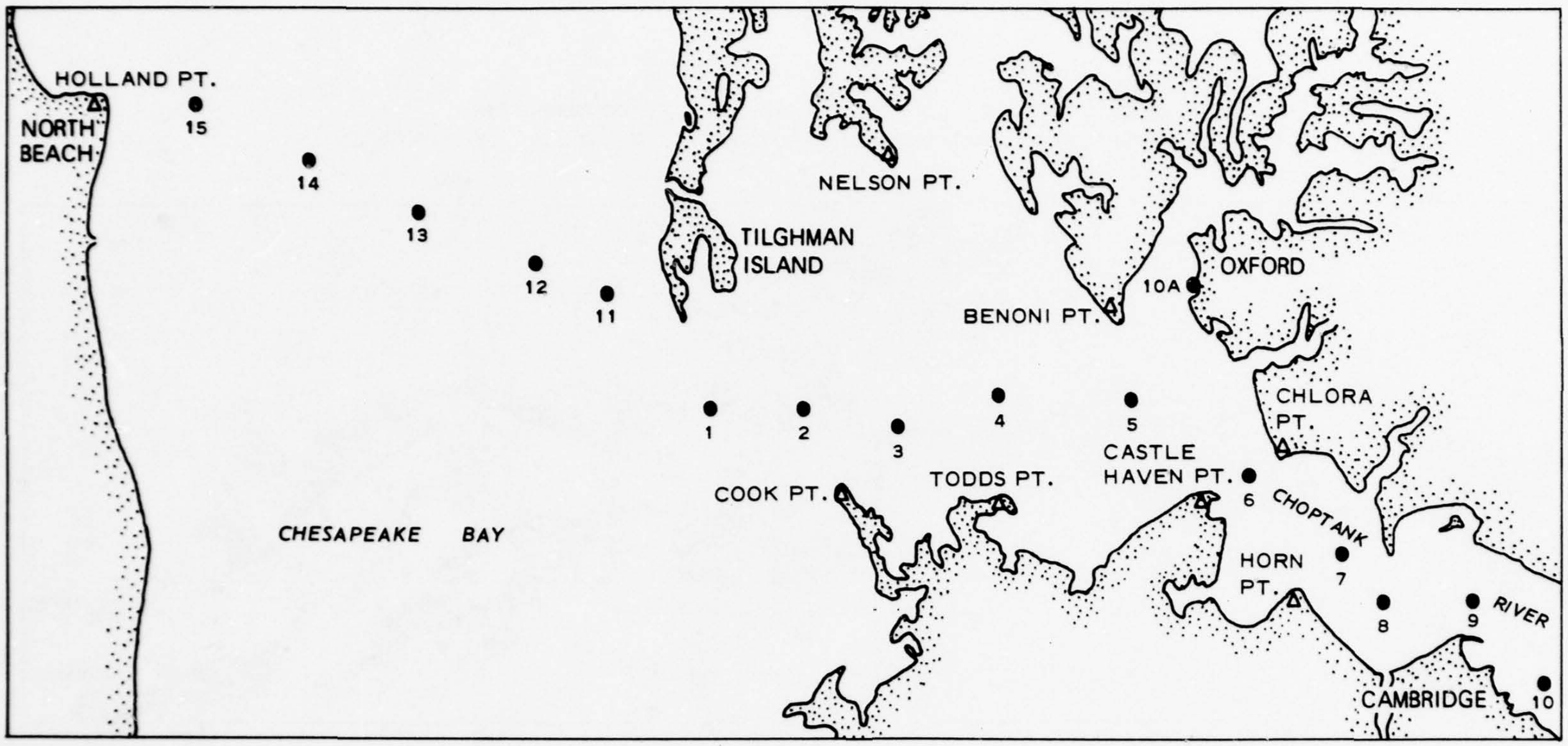

Figure 10. Location of ground control data collection stations, Choptank River and portion of Chesapeake Bay

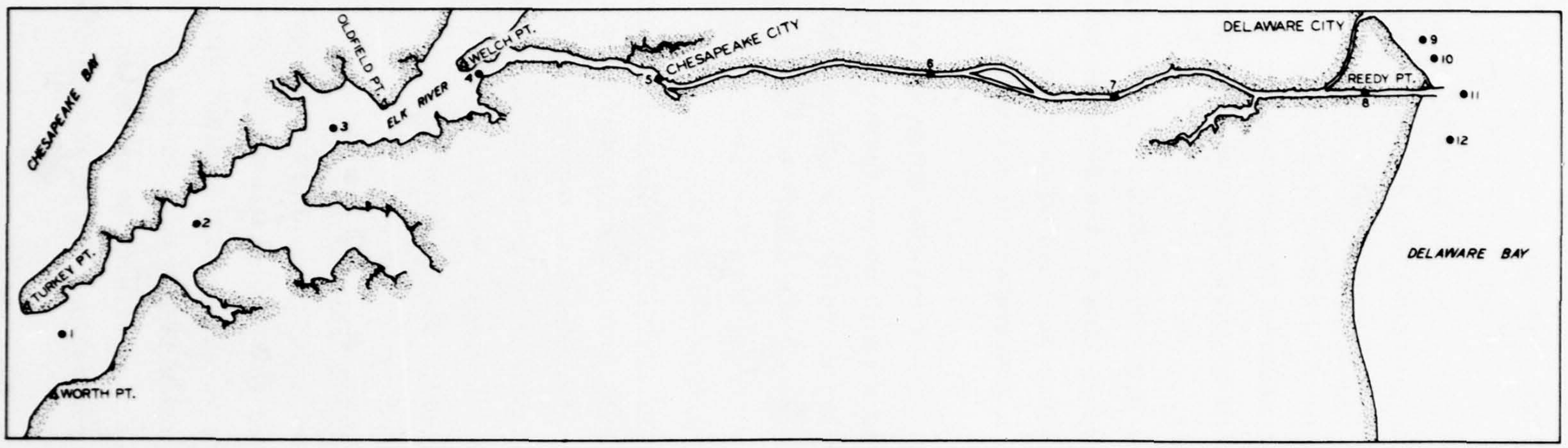

Figure 11. Location of ground control data collection stations, Chesapeake and Delaware Canal and adjacent Elk River and Delaware Bay

local conditions such as high winds and waves prevented sampling at some data collection stations. For example, sites 14 through 18 in the York River study area (Figure 7) could not be sampled because of high waves. The data collection methods are described in the following paragraphs.

63. Water current direction and speed. Current direction was approximated from observations of the boat heading while the boat was at anchor. Current speed was measured by lowering the current velocity sensor to a depth of 1 m and counting the number of propeller revolutions for a period of 2 min.

64. Secchi depth. A white 30-cm-diam. secchi disk was lowered into the water on a calibrated line to the depth at which the disk was no longer visible. This depth was then noted on the calibrated line and recorded. The result was a measurement of the water's relative optical transparency.

65. Forel Ule color. The Forel-Ule color was measured by first lowering the secchi disk to a depth of one meter (or 0.5 m if the disk was not visible at 1.0 m) and matching the apparent color of the disk as closely as possible to one of the colors of the Forel-Ule color comparator. It was necessary to use both the Forel (I to X) and the Ule (XI to XXII) scales for these measurements.

66. Water temperature, pH, conductivity, dissolved oxygen, salinity. When instruments and/or sensor probes were available, water temperature, pH, conductivity, dissolved oxygen, and salinity were measured in samples of water taken as described in paragraph 67. Measurements were made using the Interocean Systems, Model 500 monitoring system. A limited number of pH measurements were made with an Orion, Model 407 specific ion meter with a Sargent-Welch pH electrode.

Data determined from laboratory procedures

67. A review of literature concerning studies previously conducted in Chesapeake Bay indicated that the concentration of suspended materials could be expected to remain nearly constant within the top 2.0 m and vary no more than approximately 5 mg/ℓ in the top 4.0 m.[9,10] During periods of low to moderate flow within the estuaries, the fluctuations of suspended material concentrations due to resuspension caused by tidal

currents would be restricted to depths greater than about 4.0 m. These findings led to the decision to take only near-surface water samples rather than a number of samples at different depths at each data collection station, as was originally planned. This decision permitted taking samples at a substantially larger number of stations within the time frame that included the ERTS-1 overpass. Water samples were taken in a plastic bucket and transferred to a closed 7.6-liter (2-gal) plastic container for transporting to a laboratory for analysis.

68. A laboratory was provided by the Chesapeake Biological Laboratory, Institute of Marine Resources, Solomons, Maryland. Laboratory analyses included determination of suspended material concentration, and, in cases where measurements had not previously been made, salinity and dissolved oxygen. All analyses were completed within 48 hr after receipt of samples to minimize any chance for sample alterations that might affect test results.

69. Suspended material (seston) concentration. The seston was collected by continuous-flow centrifugation using a Sorvall, Model SS-3 Superspeed Centrifuge operated at 15,000 RPM. Two liters of each water sample were passed through the centrifuge at a rate of approximately 200 mℓ/min. The resulting sample of water-with-solids was then frozen for storage and transported to WES. To remove salts and other materials that may have accumulated, one liter of fresh water was then passed through the centrifuge system and discarded after each test. At WES, the concentrated sample was dried at 100°C and then weighed. The weight was then divided by the original sample volume, thus giving the suspended material concentration in mg/ℓ.

70. Salinity. Approximately 5 liters of the sample in each 7.6-liter container were filtered, and the clarified effluent was collected for determination of salinity with a specific ion electrode.

71. Dissolved oxygen. When instrumentation was not available to measure dissolved oxygen at the data collection stations, an alternate method, the Winkler titration method, was used. With this method, reagents and the procedure of the Hach Chemical Company were employed as described below.

72. Water from the sample bucket (taken as described in paragraph 67) was collected in a standard 300 ml plastic bottle, exercising great care not to create air bubbles in the process. Manganous sulfate and alkaline iodide ozide were added to the water to fix the dissolved oxygen. Sulphamic acid was then added to acidify the sample. The sample was then transported to the laboratory for the remainder of the process.

73. In the laboratory, 2 ml of starch indicator solution was added to 250 ml of the sample prepared at the data collection station and titrated with phenylarsene oxide (PAO) solution. The end point of titration occurred when the solution, previously blue, turned colorless. The number of millilitres of PAO added to reach the end point of titration was equal to the dissolved oxygen content of the sample in parts per million (ppm).

Results of Ground Data Collection

74. The results of ground data collection are listed in Table 3. The data are grouped according to study area. Station numbers in each study area correspond to the station numbers shown in Figures 7 through 11.

PART IV: ERTS-1 DATA PROCESSING TECHNIQUE

Reformatting of ERTS-1 Data

Format of computer-compatible tapes (CCT's)

75. The informational content of the CCT's was discussed previously in Part II of this report. It was pointed out (paragraphs 17 and 18) that the ERTS-1 multispectral scanner (MSS) views the earth's surface in terms of individual pixels and sequentially measures the spectral reflectance of contiguous pixels located along parallel lines normal to the orbital path of the satellite.

76. The sequence of events leading to the CCT record of a measurement is shown in Figure 12. ERTS-1 orbits from north to south and the MSS scans the earth's surface from west to east. The first pixel in a scene is therefore the pixel located in the northwest corner, and the last pixel is the one located in the southeast corner. The MSS views the radiant energy reaching it from the first pixel and separates the energy into four bands (bands 4 through 7) according to wavelength. The energy in each band is then measured and the results are converted to electrical analogs.

77. The electrical voltages are sampled, commutated, and multiplexed into a pulse-amplitude-modulated data stream. Band 7 data are then transmitted to an analog-to-digital converted for encoding. At the discretion of the ground controller, band 4, 5, and 6 data may be transmitted directly to the encoder or directed to a logarithmic signal compression amplifier and then to the encoder.[3] The entire process is repeated for each pixel in a scene and the results are telemetered to ground receiving stations.

78. The data are received at the NASA Data Processing Facility. If the band 4, 5, and 6 data are received in compressed form (as they were for scenes used in this study), the compressed data are decompressed to an expanded format wherein pixel values for bands 4 and 6 vary between 0 and 127 and band 5 values vary between 0 and 126. Band 7

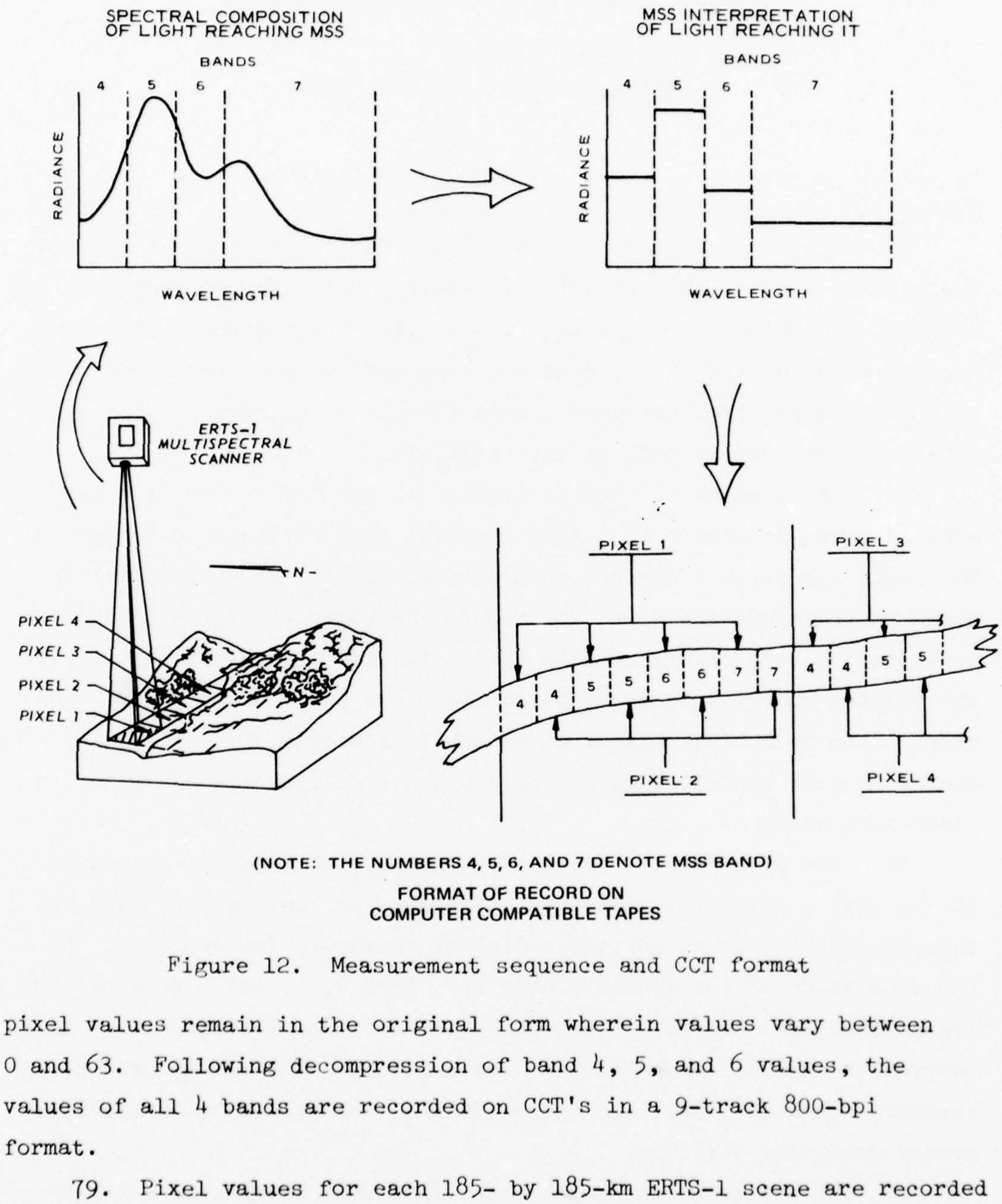

Figure 12. Measurement sequence and CCT format

pixel values remain in the original form wherein values vary between 0 and 63. Following decompression of band 4, 5, and 6 values, the values of all 4 bands are recorded on CCT's in a 9-track 800-bpi format.

79. Pixel values for each 185- by 185-km ERTS-1 scene are recorded on a set of four CCT's. Each CCT (Figure 13) contains data for an area on the ground approximately 46.3 km wide and 185 km long. The first two records on each CCT contain alph-numeric identification and annotation data. These two records are followed by 2340 binary records

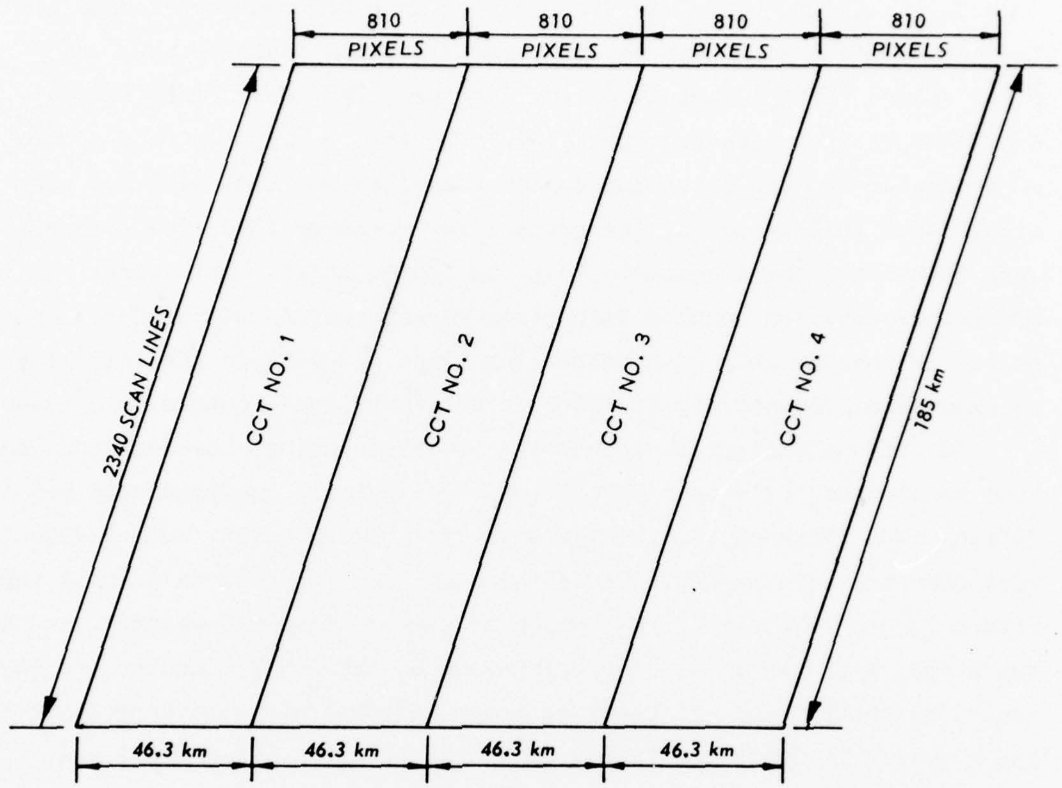

Figure 13. Distribution of MSS data on CCT's

corresponding to the 2340 scan lines in a scene. Each binary record contains values for pixels formatted as shown in Figure 12. Each pixel value is recorded in an 8-bit byte and there are 405 8-byte groups in each binary record.[3,11]

Format conversion

80. At the inception of this study, CCT's were to be processed on the Honeywell G-437 computer at the WES Automatic Data Processing Center. This computer is designed to accept data in a 24-bit word format; whereas, CCT's are recorded in an 8-bit byte format. To make the CCT values intelligible to the G-437, a program was employed to reformat the data. This program converted the data by packing groups of three pixel values into a 24-bit word and then, by shifting and unpacking data, separating each 24-bit word into three new 24-bit words--a word for each pixel value.

81. This procedure was first tested on a CCT containing data for the Lake Tahoe area. Each record (scan line) was found to have 3243 pixel values (bytes) instead of the supposed 3240, which information available at that time had specified. The last 3 bytes in each record were deleted and the shift-and-unpack technique was then used for each pixel value in the record; the process was repeated 2340 times (once for each scan line) for a complete 46.3- by 185-km strip. This time-consuming operation coupled with other eccentricities of the G-437 resulted in unacceptably long processing times, as well as the inability to examine simultaneously the data on all four tapes comprising a scene.

82. In an attempt to reduce the processing time, the decision was made to process CCT's on a PDP-15 computer that was equipped with two 7-track tape drive units, two magnetic disk memory units, and an 8000 word magnetic core memory. Since the CCT's are recorded on 9-track tape, conversion to a 7-track format was necessary.* This was accomplished in two steps, with the first step being done on the G-437 computer and the second on the PDP-15. In the first step, the 9-track data were input to the computer in words consisting of two 8-bit bytes (Figure 14) and converted to words containing three 8-bit bytes.

83. In the second step, the data were demultiplexed. In addition, the pixel values were converted back to the compressed form so that the values for all four bands would vary between 0 and 63, a requirement for later converting the pixel values on the CCT's to equivalent radiance in mW/cm^2-sr. Conversion was accomplished by applying a family of algorithms developed from the conversion table shown in Table 4. The relationships in Table 4 between decompressed and compressed data are taken from Reference 3; the method for determining equivalent radiance values is discussed in paragraph 90.

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* Two 9-track tape drive units plus an additional 8000-word core memory unit were later added to the PDP-15, resulting in expansion of processing capability and elimination of the need to convert to 7-track tapes.

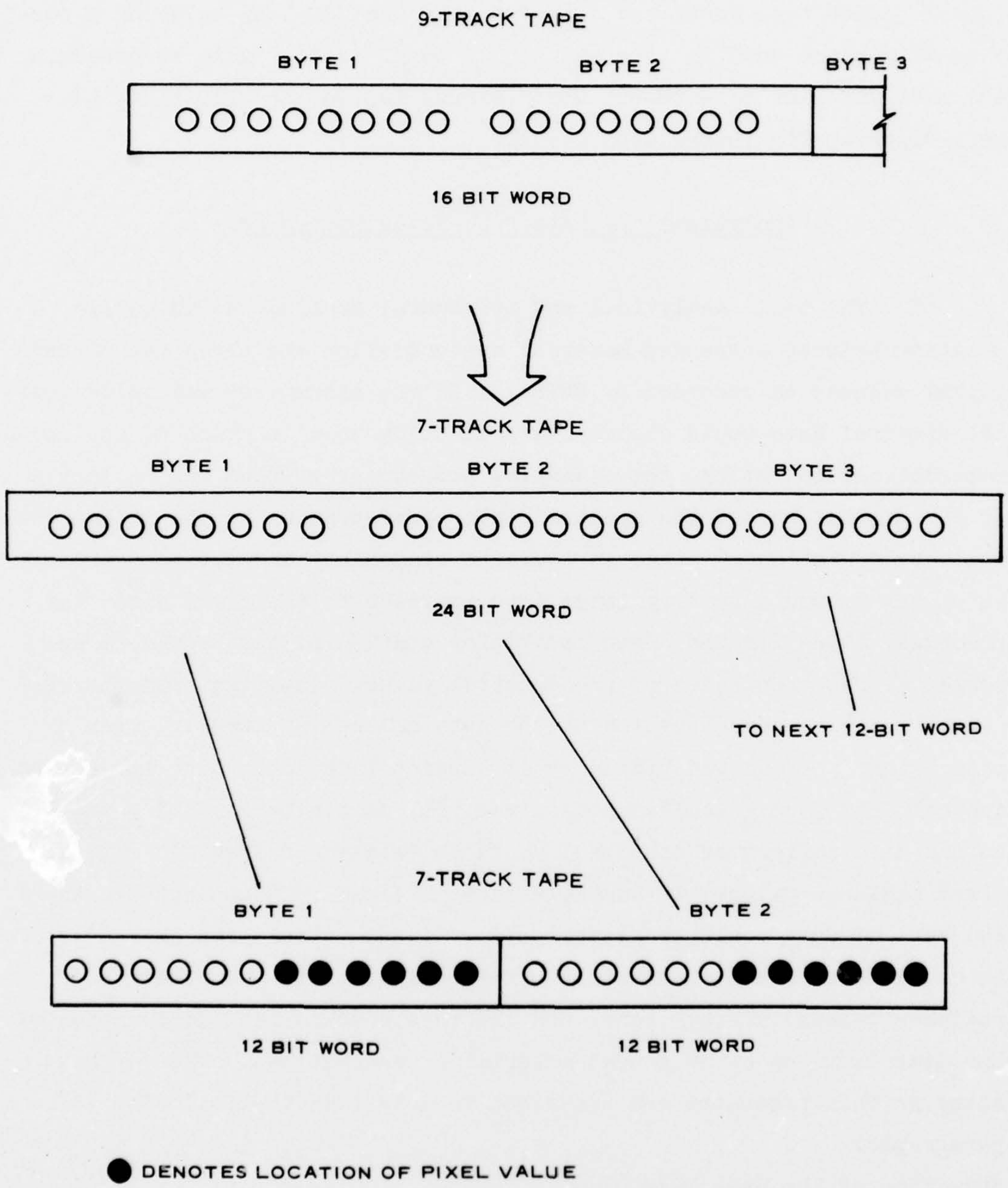


Figure 14. Conversion from 9-track to 7-track tape format

84. The demultiplexed pixel values were recorded in compressed form (values between 0 and 63) on a set of four computer tapes (input tapes). Each tape contained data for only one MSS band covering a portion of a scene 46.3 km wide and 185 km long. Values were recorded in the last six bits of a 12-bit word (Figure 14) and the first six bits were reserved for future use.

Analytical and Data Processing Procedures

85. The basic analytical and procedural problem was to develop a relation between suspended material concentration and the spectral data (pixel values) as recorded by ERTS-1. If the assumption was valid that the spectral data would change systematically as a function of suspended material concentration, the essential procedural problem was to locate in the digital record the spectral data corresponding to the ground data collection stations. Since it could be reasonably assumed that the water masses would be very large in comparison to the pixel size, the recorded values for the "data collection station pixels" could be accepted as representative of the spectral values resulting from the suspended material concentration at the data collection station, even though that station was virtually at a point location. Once the ground control data (the actual suspended material concentrations as measured at the data collection stations) could be related to specific sets of pixel radiance values, it was hoped that a fixed relation between the two sets of data could be established. If such a relation emerged, then it could be applied to all other pixel radiance sets (combination of radiance values) in the scene, and the result would be a delineation of the distributions of suspended material concentrations. The various steps in this procedure are described in detail in the following paragraphs.

Reduction of the data base size

86. Each of the five study areas comprises only a relatively small part of an ERTS-1 scene. It was therefore expedient to reduce the size of the data base to include only those portions relevant to the study

areas. This was done by isolating those scan lines that comprise each study area and masking the values for all pixels of no interest. The procedures used are discussed in the following paragraphs.

87. Isolation of area of interest. The area selected for processing was first chosen with the help of NASA-provided 1:1,000,000-scale images of the scene of interest. The four 46.3-km wide strips generated by the four CCT's were first marked on the images to facilitate selection of the proper CCT (Figure 15). The area of interest was then bounded by two lines parallel to the scan lines comprising the image.

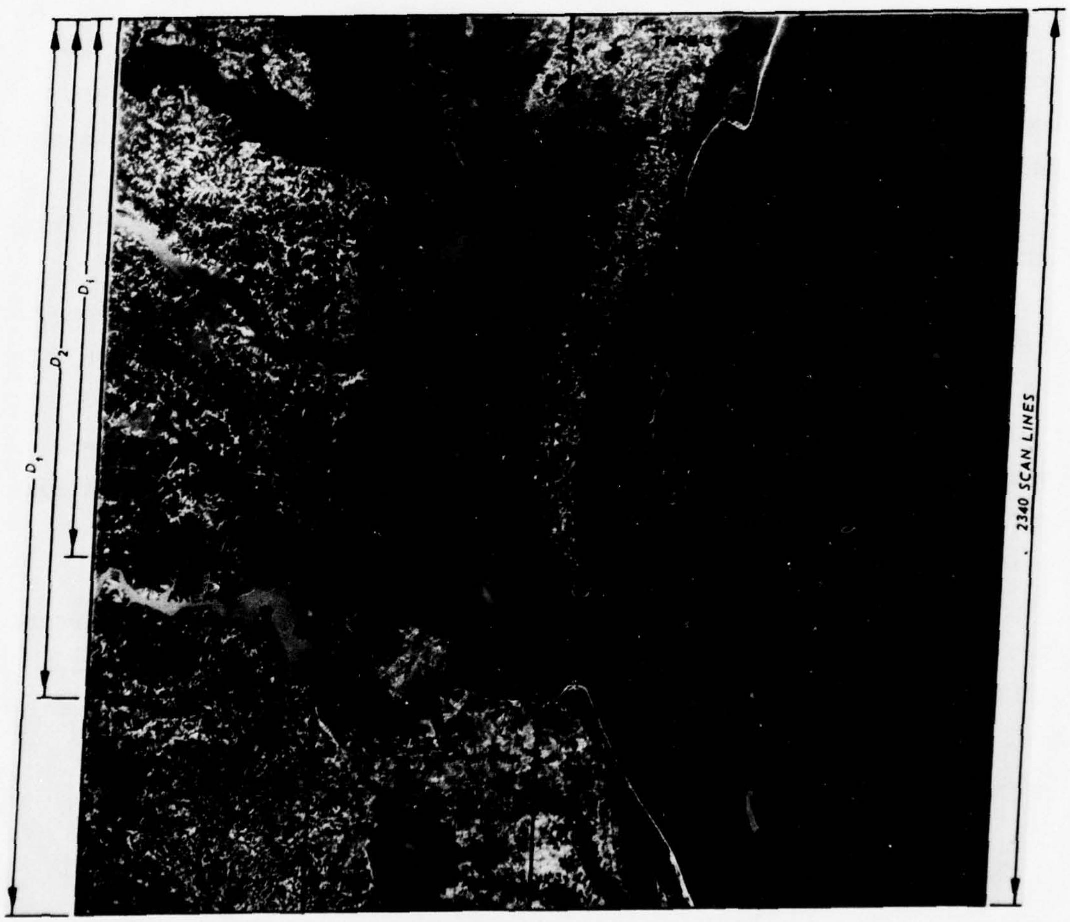


Figure 15. Selection of data for digital mapping

The two scan lines represented by the two bounding lines are identified by applying the equation

$$n = 2340 \frac{D_i}{D_t}$$

where

n = scan line number

D_i = distance in cm from top of scene to scan line of interest

D_t = total length of scene in cm

By using the equation twice, once for the top bounding line (D_1) in Figure 15 and again for the bottom bounding line (D_2), the line numbers of the two scan lines of interest are approximately identified. The identities are only approximate because the NASA-provided images are composed of 2256 scan lines while the CCT's contain 2340 scan lines of data.[3]

88. No attempt was made to limit the data base to pixels for areas less than 48.3 km (the width of a strip covered by a CCT) wide.

89. Land area masking. Since the study concerned only the concentration of suspended materials in water, the areas of interest were only the open-water areas, and thus the areas to be masked were the land areas. The first steps in this procedure were to convert the ERTS-1 data to radiometric terms (mW/cm^2-sr) and to correct for effects caused by the propagation through the earth's atmosphere of electromagnetic radiation in the four ERTS-1 bands.

90. The values recorded on the tapes vary from 0 to 63 and correspond to radiance values between 0 and the maximum value that the MSS would accept. Thus, a "63" on the tape corresponds to the maximum radiance detectable by an MSS band. Maximum radiance values for the four ERTS-1 bands are as follows:[2]

Band No.	Maximum Radiance Value
4	2.48 mW/cm^2-sr
5	2.00 mW/cm^2-sr
6	1.76 mW/cm^2-sr
7	4.60 mW/cm^2-sr

Radiance can therefore be determined from the values on the CCT's by the equation

$$H = M_i \cdot \frac{x}{63} \tag{1}$$

where

H = radiance in mW/cm^2-sr

M_i = maximum radiance value (from tabulation above)

x = value (from 0 through 63) from CCT

91. Solutions to Equation 1 give the radiance at the ERTS-1 altitude, i.e. the radiance measured by each MSS sensor. For correlation with ground control data, these data were corrected back to radiance levels at the ground (water) surface. By so doing, open water surfaces could be more reliably identified and a far more reliable basis for relating radiance data to suspended material concentration would result. Corrections were made using data reported by the Air Force Cambridge Research Laboratory.[6]

92. Researchers at the Air Force Cambridge Research Laboratory have defined model atmospheres that can be used as the basis of computation of atmospheric optical properties for tropical, midlatitude summer, midlatitude winter, subarctic summer, and subarctic winter conditions. Atmospheric properties for mid-latitude summer conditions were used in this study since the range of pressure, temperature and absorbing gas concentrations appeared to be closest to that expected in the study area in early October. Using the data in Reference 6, the atmospheric transmittance was computed as a function of wavelengths between 0.5 and 1.1 μm. The results are shown graphically in Figure 16. The solutions to Equation 1 divided by the average of the computed transmittance values (τ) for each of the MSS bands give the radiance near the ground (water). Thus, Equation 1 may be restated as follows:

$$H = \frac{M_i \cdot \frac{x}{63}}{\tau_i} \tag{2}$$

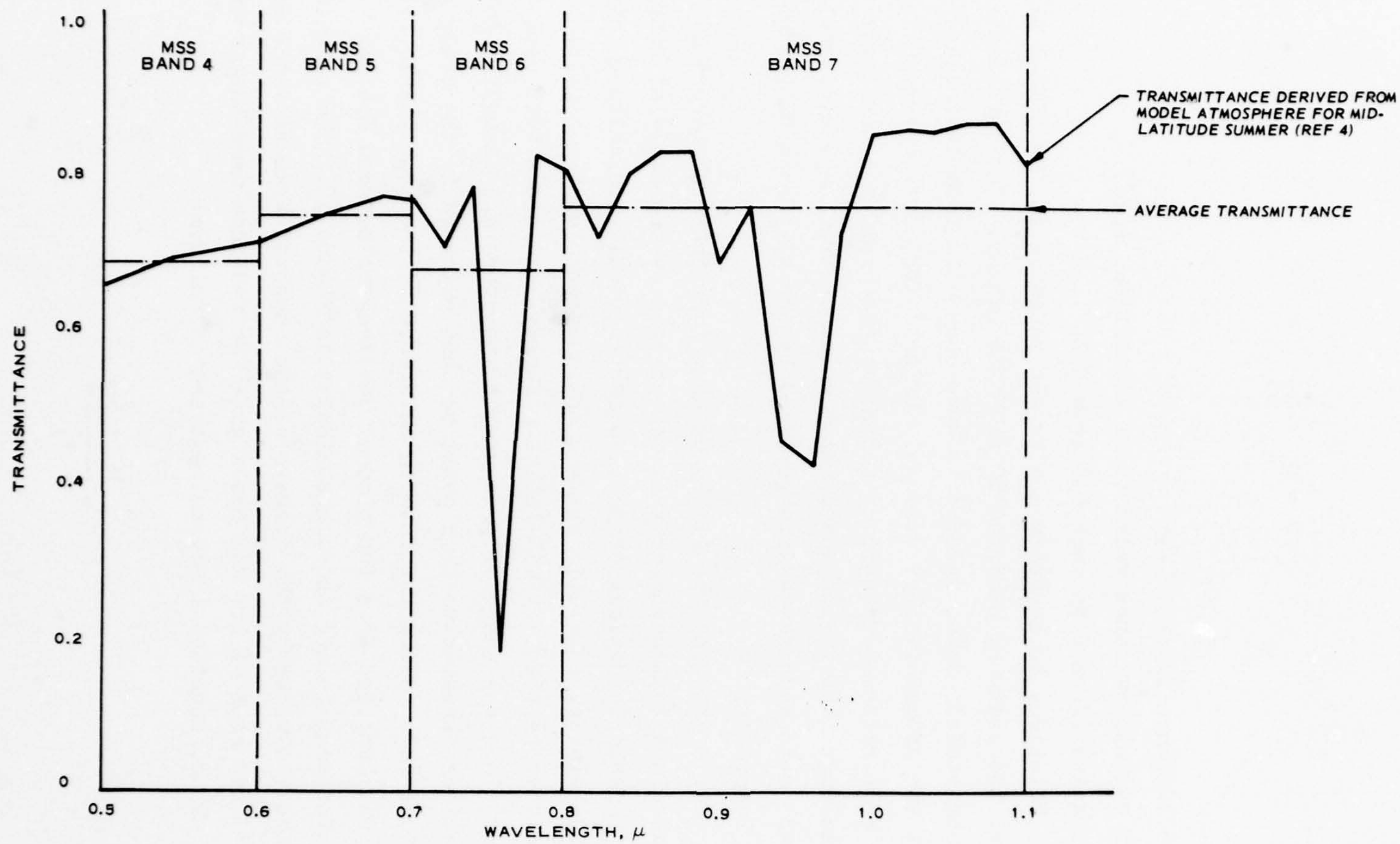


Figure 16. Transmittance versus wavelength

where τ_i = atmospheric transmittance in the appropriate MSS band and:

$$\tau_4 = 0.69$$
$$\tau_5 = 0.75$$
$$\tau_6 = 0.68$$
$$\tau_7 = 0.76$$

93. It should be noted at this point that the conversion of CCT values to near-surface radiance values serves two important purposes. First, as described in paragraphs 94-98, the converted values provide a ready and reliable method of identifying open-water surfaces. Second, with procedures discussed in paragraphs 99-111, they provide a far more reliable basis for relating radiance data to suspended material concentration.

94. The effects of water on radiation in the near-infrared region of the electromagnetic spectrum has been known and exploited for many years. The low reflectance of water bodies in the near-infrared was reported as early as 1939.[12] In 1952, G. C. Brock noted that infrared photographs are characterized by a very dark rendering of water, and that even ditches only a few feet deep record black in infrared air photos.[13] Other authors have noted that water bodies are more sharply defined against various terrain backgrounds in infrared air photos than in panchromatic photos.[14,15]

95. The infrared wavelengths referred to by these authors are those to which near-infrared films are responsive; the range is normally from about 0.7 to 0.86 μm.[16] Similar responses have been observed in ERTS-1 data for MSS band 7 (0.8 to 1.1 μm). In Figure 17, the ERTS-1 image for band 7 shows Chesapeake Bay, Delaware Bay, and the Atlantic Ocean as black against various shades of gray that correspond to land areas. The computer printout on the figure shows radiance values (computed from Equation 2) corresponding to the small box on the image. Note that the radiance values for pixels over water are less than 0.2 mW/cm^2-sr and significantly less than values over land, which are as high as 2.88 mW/cm^2-sr.

96. Since band 7 radiance values for "water" pixels are

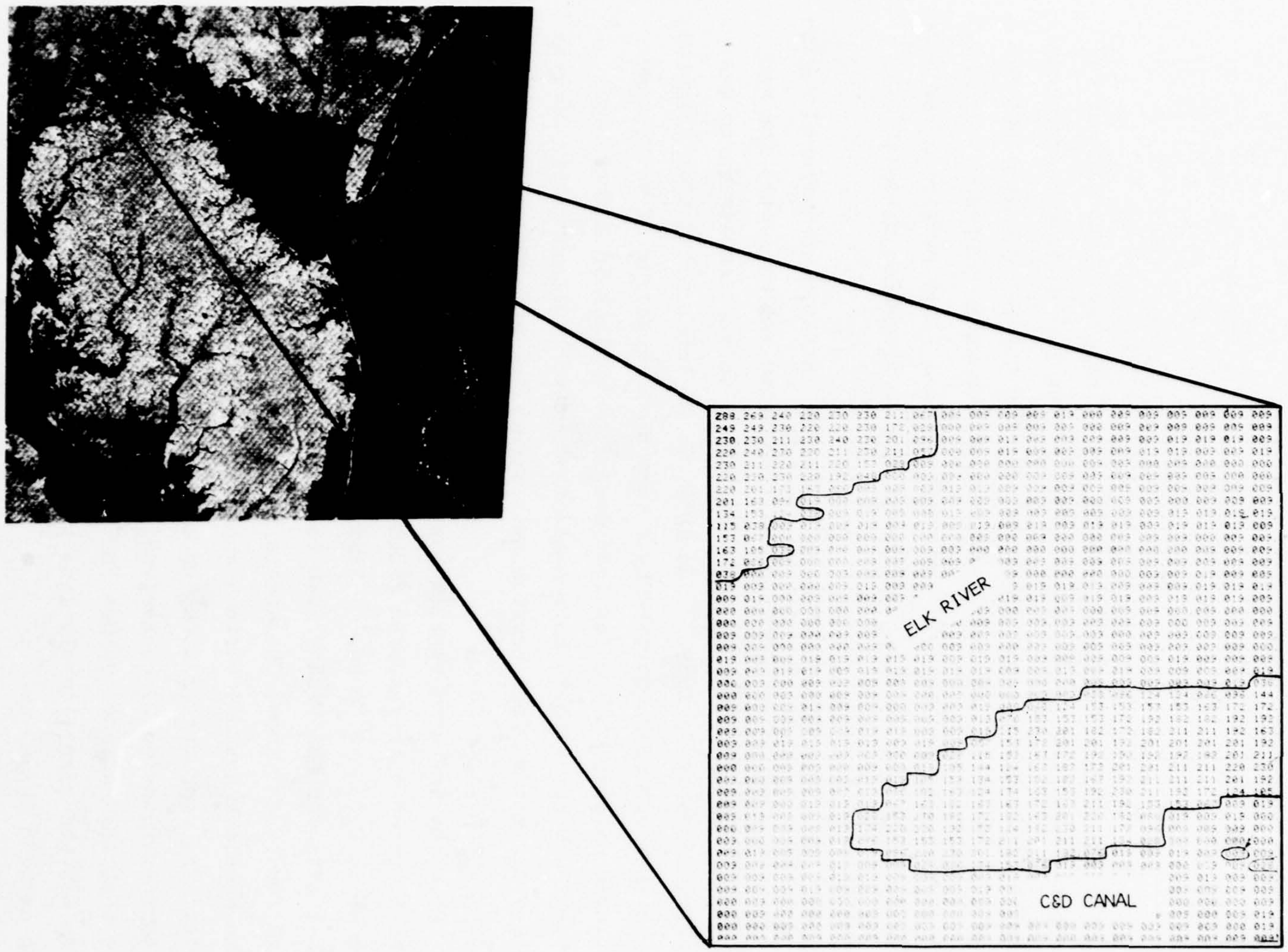


Figure 17. Image and array of radiance values derived from MSS band-7 data

characteristically so much lower than the radiance values of "land" pixels, the data in this band provide a convenient way to digitally identify "water" pixels. A computer program was therefore formulated that interrogates each band 7 radiance value. If the radiance value is less than 0.2 mW/cm^2-sr, a binary "1" is placed in the first (most significant) bit position of the 12-bit word containing the pixel value (Figure 18). All other pixels have a "0" in this bit position.

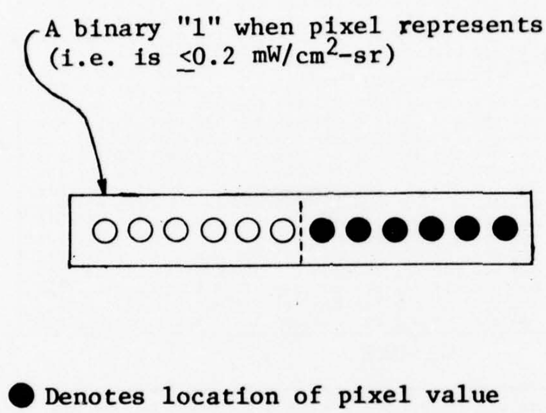


Figure 18. Identification of water pixels

97. The immediate practical value of the ability to discriminate "water" from "land" pixels is that the "land" pixels can be left out of all subsequent processing steps. That is, band-7 pixels that have been identified as pertaining to land serve as a digital mask that inhibits processing of those same pixels in bands 4, 5, and 6. The procedure is to place the first scan line of bands 7 (the infrared band) and 4 in memory. The first bit position of pixel 1 (Figure 18) in band 7 is interrogated. If the value is a 1, then pixel 1 represents water, and pixel 1 in band 4 is retained for further processing. However, if the first bit is a zero, then pixel 1 represents land, and the data for pixel 1 in band 4 is, in effect, erased. This process is repeated for each pixel, with the result that only "water" pixel data are retained in the record for band 4. The same process is repeated for bands 5 and 6.

98. The effect of this is shown in Figure 19. Each radiance value shown corresponds to a pixel and has a corresponding value for each MSS

000	000	009	019	009	009	019	019	019	019	019	019	009	009	009	019	019
000	009	009	009	009	009	019	009	019	019	009	019	019	009	019	019	019
000	000	000	000	009	000	009	009	000	009	009	000	009	009	000	009	000
000	000	000	000	009	009	000	009	009	009	009	009	009	009	000	009	009
009	000	009	009	009	009	009	009	009	009	009	009	000	009	009	009	009
000	000	000	009	000	000	009	009	000	009	009	009	009	009	009	009	009
009	019	019	019	019	019	009	019	019	009	009	009	009	009	019	009	009
019	019	009	019	019	019	019	019	009	009	019	009	019	009	009	009	009
000	009	009	009	009	009	000	009	009	000	000	009	009	009	009	009	019
009	000	009	009	009	000	009	000	000	009	009	028	096	124	124	086	096
009	019	009	009	000	009	009	019	009	048	124	153	153	153	153	163	172
009	009	009	009	009	009	009	019	076	153	153	153	172	192	182	182	192
009	009	009	019	019	009	009	019	115	230	201	182	172	182	211	211	192
019	019	019	019	009	019	009	057	153	172	201	201	192	201	201	201	201
000	009	009	009	000	009	[illegible]	115	153	163	172	192	192	192	192	182	201
009	009	000	009	000	019	[illegible]	144	124	163	182	172	201	201	211	211	220
009	009	009	019	019	105	153	134	153	182	182	163	192	211	211	211	201
009	009	009	019	086	182	163	124	134	163	153	192	230	211	192	172	124
000	019	019	019	067	163	182	163	163	172	163	211	192	153	153	067	009
009	009	019	028	153	230	192	172	182	167	201	220	182	086	019	009	019
009	009	019	124	220	220	192	153	124	182	220	211	172	096	009	009	009
009	009	019	086	153	153	153	172	211	201	211	211	174	028	000	000	000
009	009	009	019	096	220	230	201	182	211	182	076	019	009	019	009	
009	009	019	009	009	028	086	174	153	076	019	009	009	009	000	009	009
009	009	019	019	009	009	009	009	019	009	009	009	019	009	009	019	009
009	019	009	009	009	009	009	019	009	009	009	009	009	009	009	009	009
000	000	000	000	000	000	000	000	000	009	009	000	000	009	000	000	000
000	000	000	009	000	000	000	009	009	009	009	009	000	000	009	000	009
009	000	009	009	009	009	009	009	009	009	000	009	009	009	009	009	000
000	009	000	009	009	000	000	009	009	009	000	009	009	009	009	009	009
009	009	009	009	009	009	009	009	009	009	009	009	009	009	019	019	019
019	009	019	009	009	009	009	009	009	009	009	009	009	019	019	009	019
000	000	009	000	000	000	000	000	000	009	000	000	009	009	000	009	038
000	009	009	000	000	000	009	000	000	000	000	000	000	009	009	048	144
000	009	000	009	000	000	009	009	009	000	000	009	009	019	009	028	076
009	009	000	009	000	000	000	009	009	009	000	009	009	009	009	009	009
009	009	019	009	019	009	019	009	009	009	009	019	019	009	019	028	028
009	009	009	009	009	019	009	009	019	009	009	019	009	009	019	048	076
009	000	009	009	000	009	009	009	009	009	009	009	009	009	009	048	076

BEFORE

000	000	009	019	009	009	019	019	019	019	019	019	009	009	009	019	019
000	009	009	009	009	009	019	009	019	019	009	019	019	009	019	019	019
000	000	000	000	009	000	009	009	000	009	009	000	009	009	000	009	000
000	000	000	000	009	009	000	009	009	009	009	009	009	009	000	009	009
009	000	009	009	009	009	009	009	009	009	009	009	000	009	009	009	009
000	000	000	009	000	000	009	009	000	009	009	009	009	009	009	009	009
009	019	019	019	019	019	009	019	019	009	009	009	009	009	019	009	009
019	019	009	019	019	019	019	019	009	009	019	009	019	009	009	009	009
000	009	009	009	009	009	000	009	009	000	000	009	009	009	009	009	019
009	000	009	009	009	000	009	000	009	009	009						
009	019	009	009	000	009	009	019	009								
009	009	009	009	009	009	009	019									
009	009	009	019	019	009	009	019									
019	019	019	019	009	019	009										
000	009	009	009	000	009											
009	009	000	009	000	019											
009	009	009	019	019												
009	009	009	019													
000	019	019	019													009
009	009	019													019	009	019
009	009	019												009	009	009
009	009	019												000	000	000
009	009	009	019									019	009	019	009	
009	009	019	009	009						019	009	009	009	000	009	009
009	009	019	019	009	009	009	009	019	009	009	009	019	009	009	019	009
009	019	009	009	009	009	009	019	009	009	009	009	009	009	009	009	009
000	000	000	000	000	000	000	000	000	009	009	000	000	009	000	000	000
000	000	000	009	000	000	000	009	009	009	009	009	000	000	009	000	009
009	000	009	009	009	009	009	009	009	009	000	009	009	009	009	009	000
000	009	000	009	000	000	000	009	009	009	000	009	009	009	009	009	009
009	009	009	069	009	009	009	009	009	009	009	009	009	009	019	019	019
019	009	019	009	009	009	009	009	009	009	009	009	009	019	019	009	019
000	000	000	000	000	000	000	000	000	009	000	000	009	009	000	009	
000	009	009	000	000	000	009	000	000	000	000	000	000	009	009		
000	009	000	009	000	000	009	009	009	000	000	009	009	019	009		
009	009	000	009	000	000	000	009	009	009	000	009	009	009	009	009	009
009	009	019	009	019	009	019	009	009	009	009	019	019	009	019		
009	009	009	009	009	019	009	009	019	009	009	019	009	009	019		
009	000	009	009	000	009	009	009	009	009	009	009	009	009	009		

AFTER

NOTE: PRINTED VALUES X .01 = RADIANCE IN MW/CM^2-SR

Figure 19. Results of digital masking

band. By applying the mask, values for water pixels have been printed, and a blank has been left where land pixels would otherwise have been located.

Development of suspended sediment concentration mapping criteria

99. Production of digital maps. Digital maps were comprised of radiance values for all "water" pixels within an area. The area was 810 pixels wide (one-fourth of a scene) and was described by scan lines isolated according to the procedure previously described in paragraph 87. To make digital maps, the radiance values of each "water" pixel were printed; a computer-interfaced line printer that prints only 20 radiance values per line was the only equipment readily available to do this. So that the strips could be combined to make a map, each 810-pixel scan line of radiance values was divided into 40 groups with 20 radiance values per group and one group with only 10 radiance values. Then the data in each group were printed out on a separate strip. When the strips were hung on the wall vertically in juxtaposition (with the margins overlapping), the result was a digital map approximately 8.75 m wide. A 2.4-m-high wall could accommodate about 575 scan lines of data.

100. Location of pixels representing data collection points. As mentioned earlier, the establishment of reference spectra, i.e. the establishment of the relations among suspended material concentrations and radiance values in bands 4, 5, and 6, depends on identifying the pixels that encompass the various data collection stations. Since these were always in water bodies, and in many cases far from land reference points, the identifications were neither easy nor in every case positive. The difficulty was to some degree compounded by the fact that the digital maps, because of character size and spacing limitations of the line printer, were badly distorted. For example, a 200-pixel array represents an area about 1140 m wide by 1580 m long; whereas, the line printer presents the same array by a printout that is about 125 units wide and 53 units long. To retain the same scalar relation, the printout should be some 173.5 units long, or more than three times the actual value.

101. The general procedure was first to locate each data collection station as accurately as possible on a suitable map or navigation chart. The locations of the stations were fixed in the field by reference to two or more landscape features, such as a bridge, a point of land, the tip of an island, and so on. In every case, the features were chosen so that they could be readily identified on a map. The data for each station included distance and direction to each reference feature. These data were then used to fix the location of each data collection station on a large-scale map.

102. The same reference features were then identified as closely as possible on the digital maps. Angles and distances were of course distorted by the distortions introduced by the line printer, but since the scalar relations were known, the angles and distances on the maps could be transformed to values appropriate to the digital maps. There are of course errors in all such procedures. While the errors could not be estimated precisely, the order of magnitude is believed to be not more than 100 m. That is, the true position of a data collection point, as located on the digital map, is no greater than 100 m in any direction from the position identified. Schematically, this situation appears as illustrated in Figure 20. If the location of the data collection station is assumed at pixel center there is a reasonable chance that the data collection station is actually located in any one of nine pixels, but the true pixel cannot be reliably determined.

103. In view of this, at least three options were open. First, the central pixel of the array of nine possible pixels (Figure 20) could be accepted on the grounds that it represented the highest probability. Second, the average of the radiance values of all nine pixels could be calculated and used as the "true" value. Third, the radiance values of the nine pixels could be examined; if several of them clustered closely around a single set of values (as they did, in most instances), one of those exhibiting values closest to the mode of the set could be selected as representative. In practice, a modification of the second option was actually used because of the occurrence of spurious radiance values resulting from MSS system "noise." Sources of "noise" are discussed in

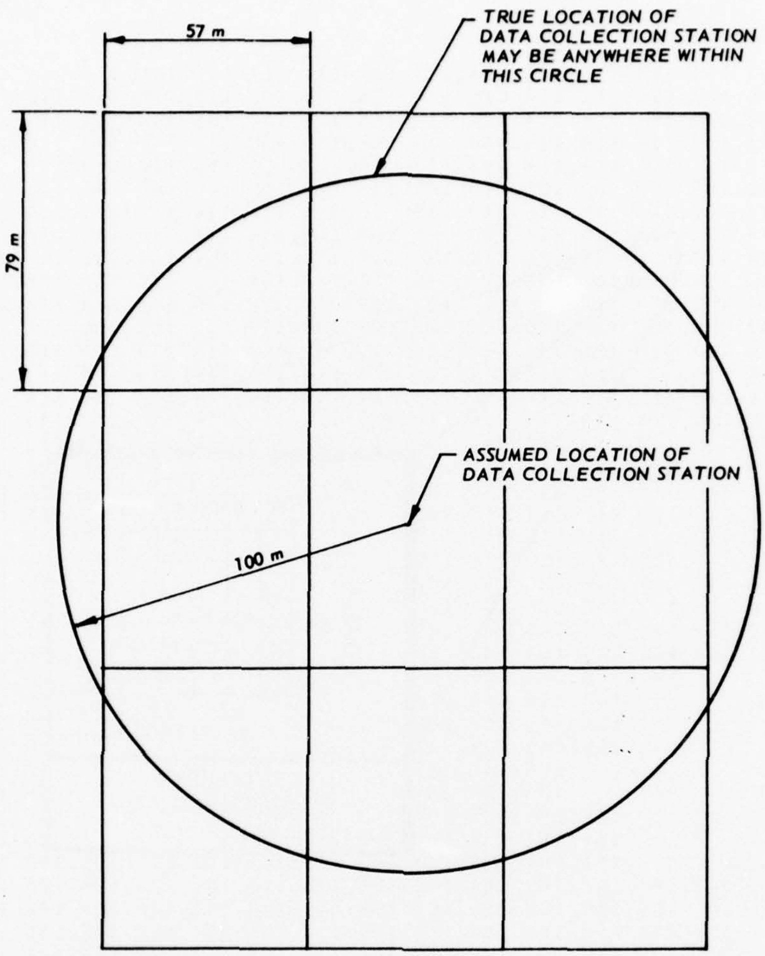
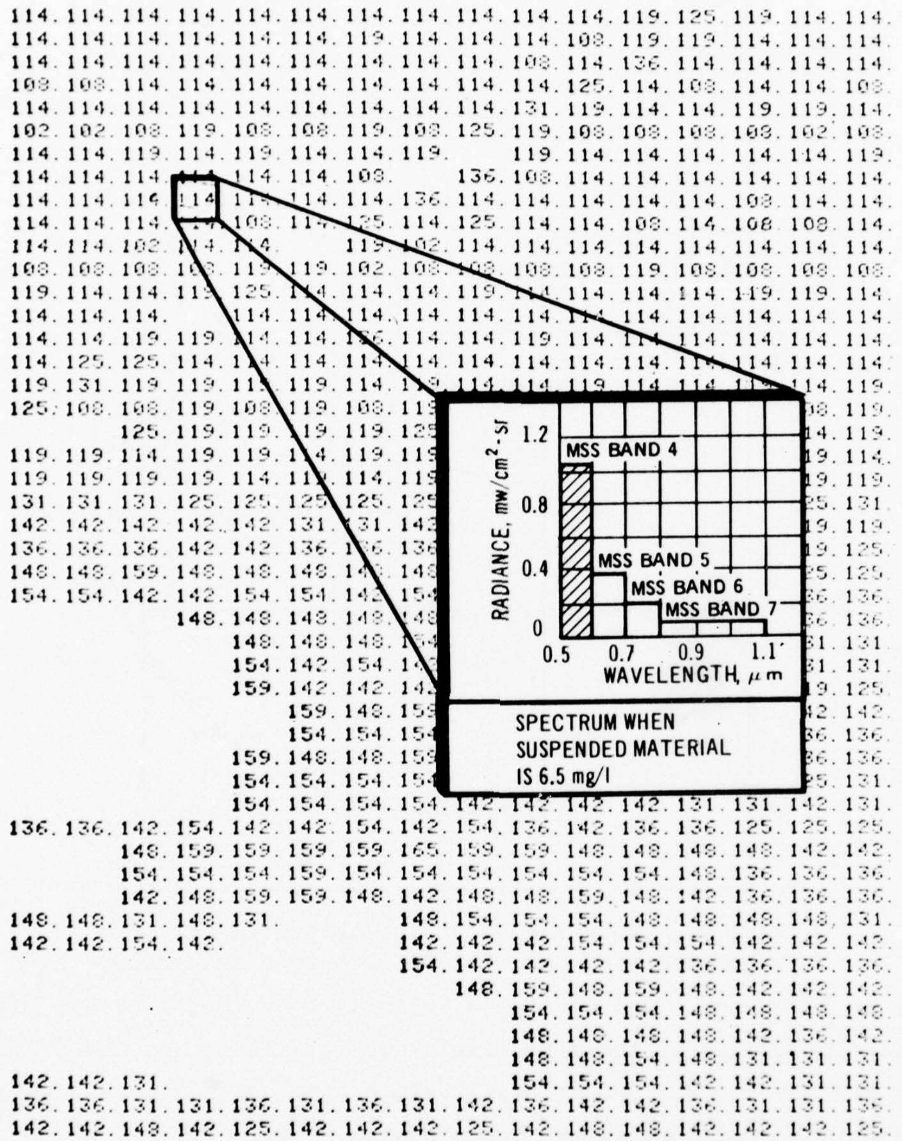


Figure 20. Possible error in positioning of data collection stations with respect to pixel grid

detail in Reference 3 and mentioned in paragraphs 106, 109, and 113. The radiance values of the nine pixels were examined, and the average of the highest and the lowest pixel values (including pixels with noise) was calculated and used as the "true" value.

104. Correlation of radiance values with suspended material concentrations. Once the pixel representing the data collection station (the central pixel of the array of nine possible pixels) had been selected, it could readily be identified by strip, line, and column numbers. Then, if the selection had been made from a band 4 digital map, for example, the same position in the digital maps representing the radiance values in bands 5 and 6 could be readily identified. Figure 21



NOTE: PRINTED VALUES X .01 = RADIANCE IN MW/CM^2-SR

Figure 21. Portion of digital map showing reference spectrum for ground data collection station in Rappahannock River

is a portion of a band 4 digital map of the Rappahannock River. The numbers on the map multiplied by 0.01 give the radiance in mW/cm^2-sr. The small square denotes the location of a ground data collection station where the suspended material concentration was found to be 6.5 mg/ℓ.

The radiance at this location on the digital map was found to be 1.14 mW/cm^2-sr. Considering this value and the eight values contiguous to this value on the digital map, high and low values of 1.14- and 1.08-mW/cm^2-sr were found. The average of these values, 1.11 mW/cm^2-sr, was considered to be the "true" value. Corresponding values for MSS bands 5, 6, and 7 were determined in this manner and were combined with the band-4 value to define the spectrum for the case where the suspended material concentration is 6.5 mg/ℓ. The band-7 value is shown in this example for information only and is not used in subsequent analysis except for land-water pixel identifications. Correlations of band-4, -5, and -6 "true" radiance values with suspended material concentrations at the various data collection stations are given in Table 5.

105. By sheer chance, the data for the York River were analyzed first. When the radiance values for each MSS band were plotted as a function of suspended material concentration (see Figure 22), it was noted immediately that nearly all of the data points fell along linear trends, but that two of them, stations 9 and 13, appeared to be anomalous.

106. On the basis of these considerations, radiance values in band 4, 5, and 6 should increase with increasing concentrations of suspended materials. Thus, a set of data in which the radiance values in one or more of the bands <u>decreased</u> with increasing suspended material concentrations would be suspect. Such a situation could be interpreted as revealing the influence of factors other than suspended material concentrations, and the data would therefore be unacceptable. Other possible causes of spectral anomalies might be one or more of the following situations:

- a. The station might be in a location where a different kind of suspended material occurred. This might yield quite different spectral values even though the concentration was identical.
- b. The water might be so shallow that a significant amount of light is reflected from the bottom. This might also yield a different array of spectral data.
- c. The data collection station might be in the shadow of a cloud or bridge at the time of the ERTS-1 overpass. In

general, this would be expected to yield abnormally low radiance values in all spectral bands.

d. Data collection stations close to shore might be affected by secondary reflectance from shoreline features or structures, such as cliffs, trees, or buildings. In this case, the radiance values might be expected to be too high, as well as possibly shifted in color. The evidence of the latter might be abnormally high radiance values in only one or two bands.

e. The pixel selected to represent the data collection point might be subject to instrumental "noise," in which case the values might well be both spurious and erratic. This situation was expected, since the NASA-provided images clearly revealed that about every sixth scan line (and sometimes the two neighboring lines) consisted of spurious data indicated by marked streaks across the images. Thus, purely on the basis of probability, one out of every six data collection stations should be represented by a pixel subject to "sixth-line noise."

f. Wave action might result in more specular reflectance from the surface in some situations. Since specular reflectance would consist of all frequencies, it would be expected that the radiance values in all bands would be abnormally high.

107. The York River data were re-evaluated in terms of the above criteria and those data that met one or more of the criteria were rejected. As a result, station 2, 9 and 13 in the York River, were rejected and omitted from all subsequent analysis.

108. The results of this and similar evaluations for the other study areas are shown in Table 6. It should be noted that at least two of the study areas (the Choptank River and the C&D Canal) exhibit two different types of material. The radiance values for station 7-12 in the C&D Canal, however, did not show sufficient increase with increasing suspended material concentration to permit selection of suspended material concentration classes and class ranges as described in paragraph 110 and were therefore omitted from subsequent analysis. In addition, it should be noted that "contamination" of the data due to mixing with Chesapeake Bay water is indicated at some points in the Rappahannock, Wicomico, and Choptank Rivers.

109. Radiance values for each MSS band are plotted as a function

of suspended material concentration for the York River in Figure 22. Radiance values are plotted as a function of suspended material concentration for the Wicomico, Rappahannock, and Choptank Rivers, and the Chesapeake and Delaware Canal in Figures 23-27. Those data that had been rejected are included in the plots, and are denoted by open circles. All other data are denoted by closed circles. The "accepted" data were then analyzed by linear regression on the radiance versus suspended material concentration. The solid lines in Figure 22 are the regression line for band 4, 5, and 6 data. The dashed lines on either side of and parallel to the calculated regression lines in Figure 22 and Figures 23-27 define the MSS error band, the width of which is ± 2 percent of the full scale radiance of the MSS band involved.[2] The MSS error bands are as follows:

- a. Band 4: ± 0.05 mW/cm^2-sr
- b. Band 5: ± 0.04 mW/cm^2-sr
- c. Band 6: ± 0.04 mW/cm^2-sr

110. Selection of suspended material concentration and class ranges. In Figures 22-27, six suspended material types were characterized by a set of linear relations among radiance values in band 4, 5, and 6 and suspended material concentration. Two materials in the Choptank River had spectral "signatures" sufficiently different to be differentiated on the basis of band 4, 5, and 6 data (see Figures 25 and 26). Further, radiance values for each suspended material type increased sufficiently with increasing suspended material concentration to permit spectral differentiation of material concentration on the basis of band 4, 5, and 6 data providing compensation could be made for affects of MSS error (± 2 percent of full scale for each band). To permit suspended material concentrations to be differentiated, and at the same time account for MSS error, the relations among the band 4, 5, and 6 radiance values and suspended material concentrations for each material type were separated into classes. Selection of suspended material concentration classes and class ranges was governed by the following:

- a. The number of different classes was reasonable for the range of suspended material concentration and the rate

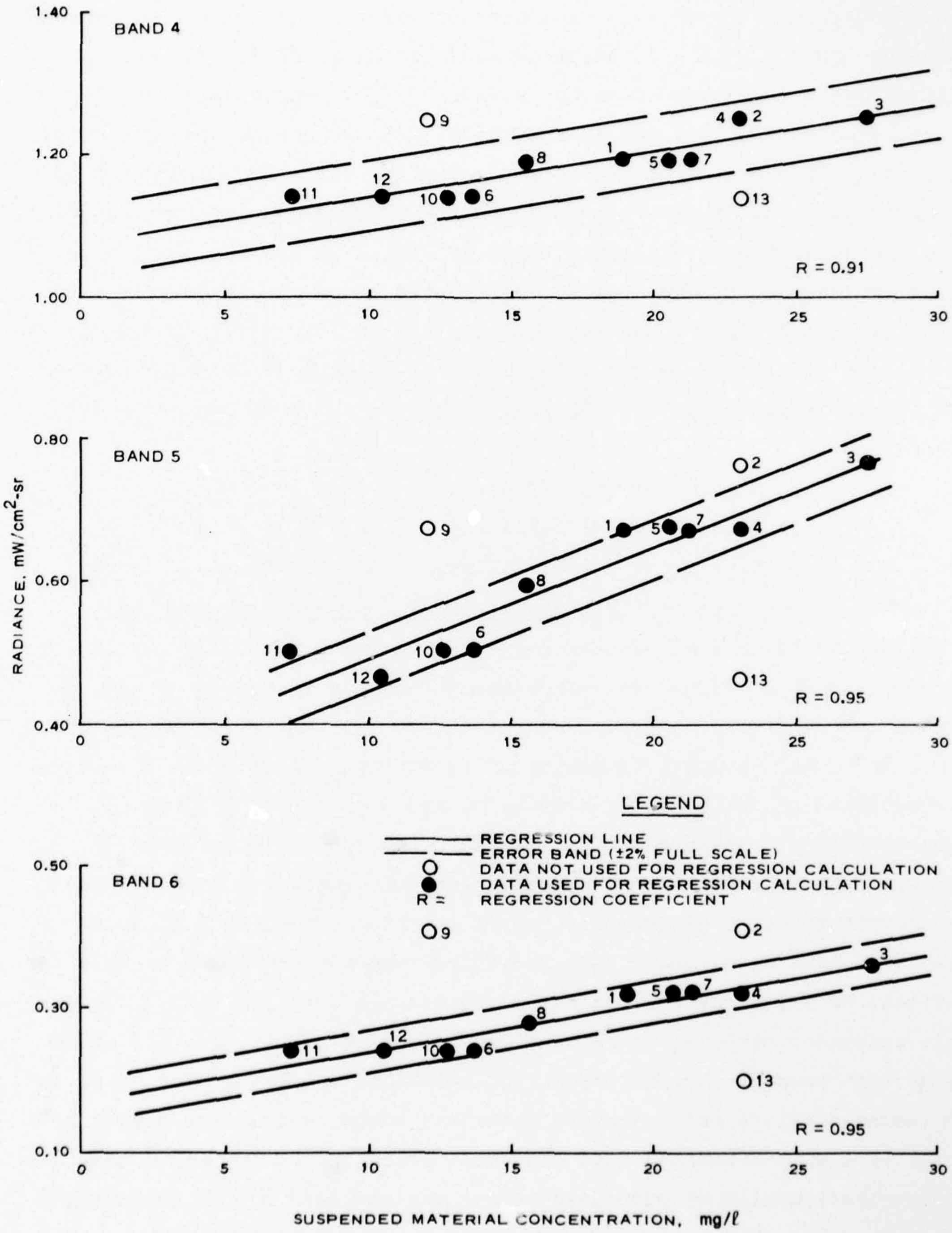


Figure 22. Radiance versus suspended material concentration, York River

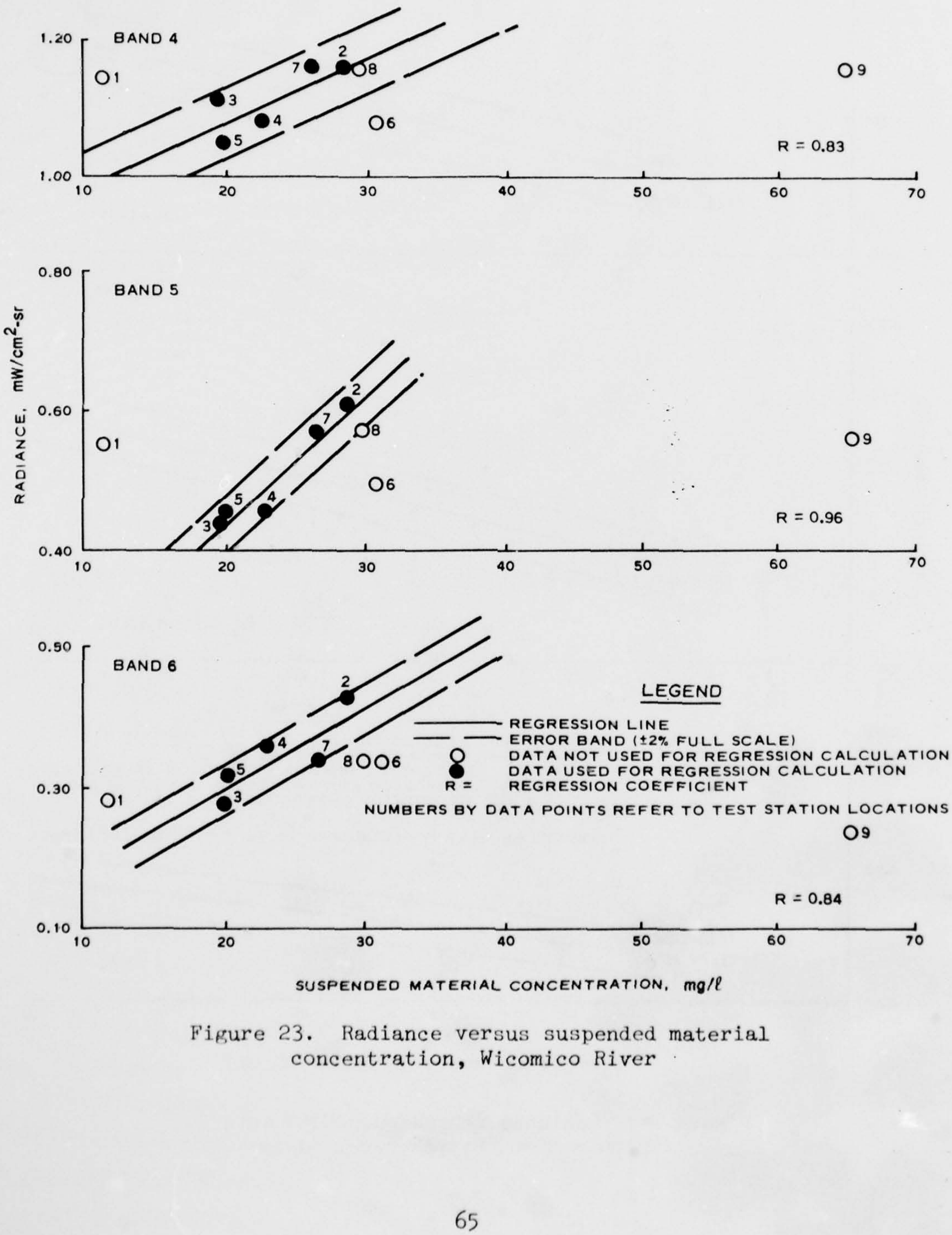


Figure 23. Radiance versus suspended material concentration, Wicomico River

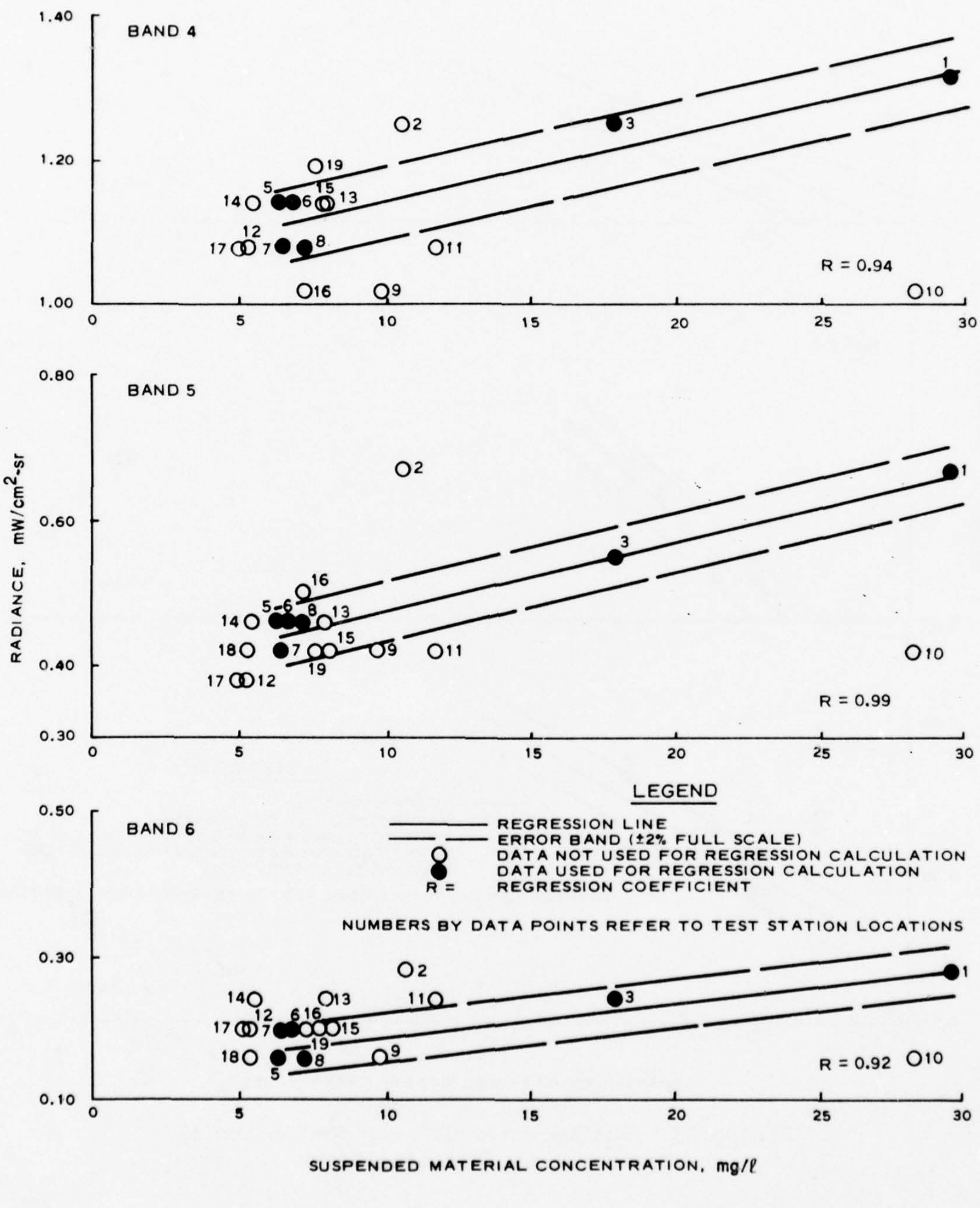


Figure 24. Radiance versus suspended material concentration, Rappahannock River

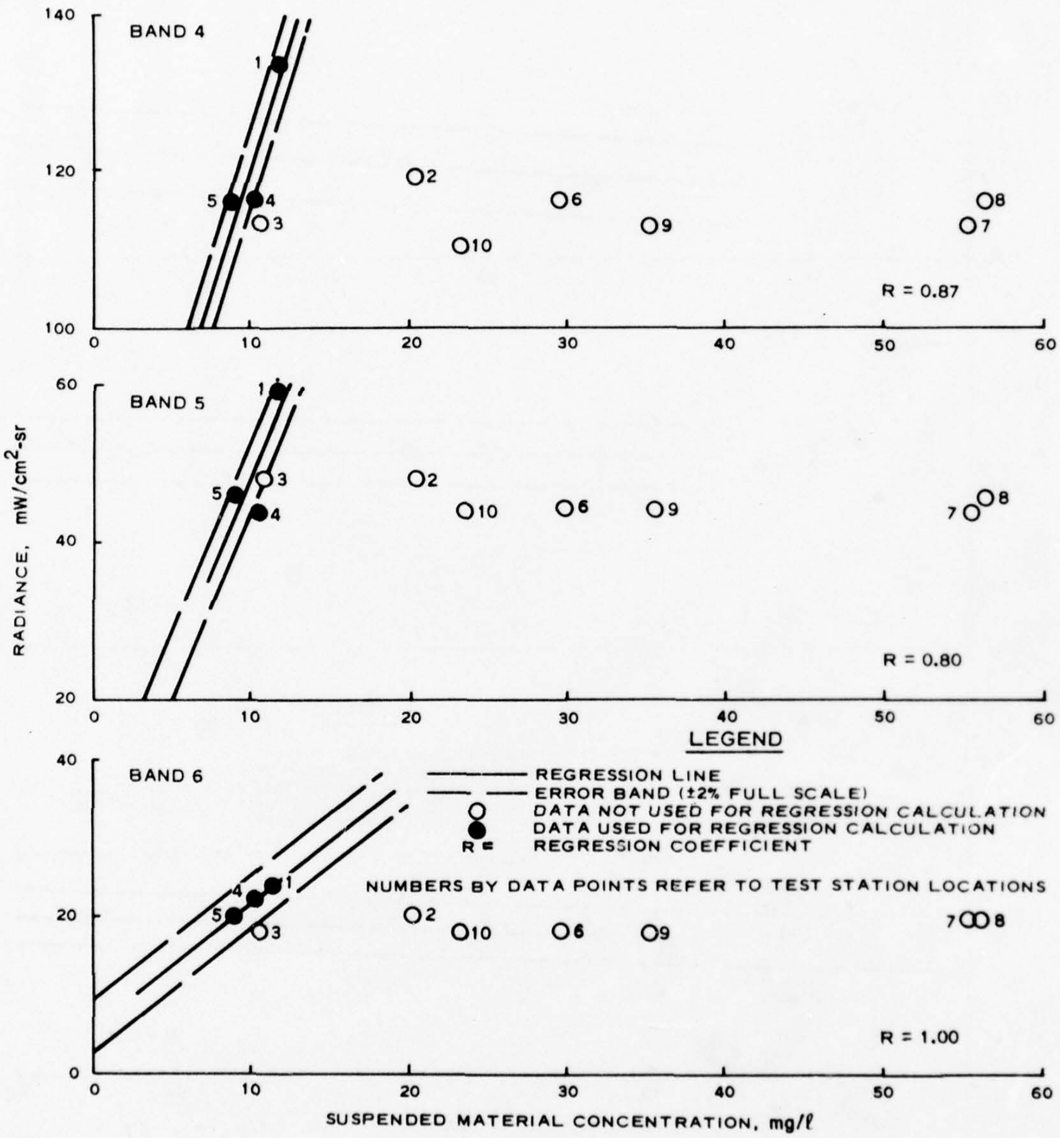


Figure 25. Radiance versus suspended material concentration Choptank River (population No. 1)

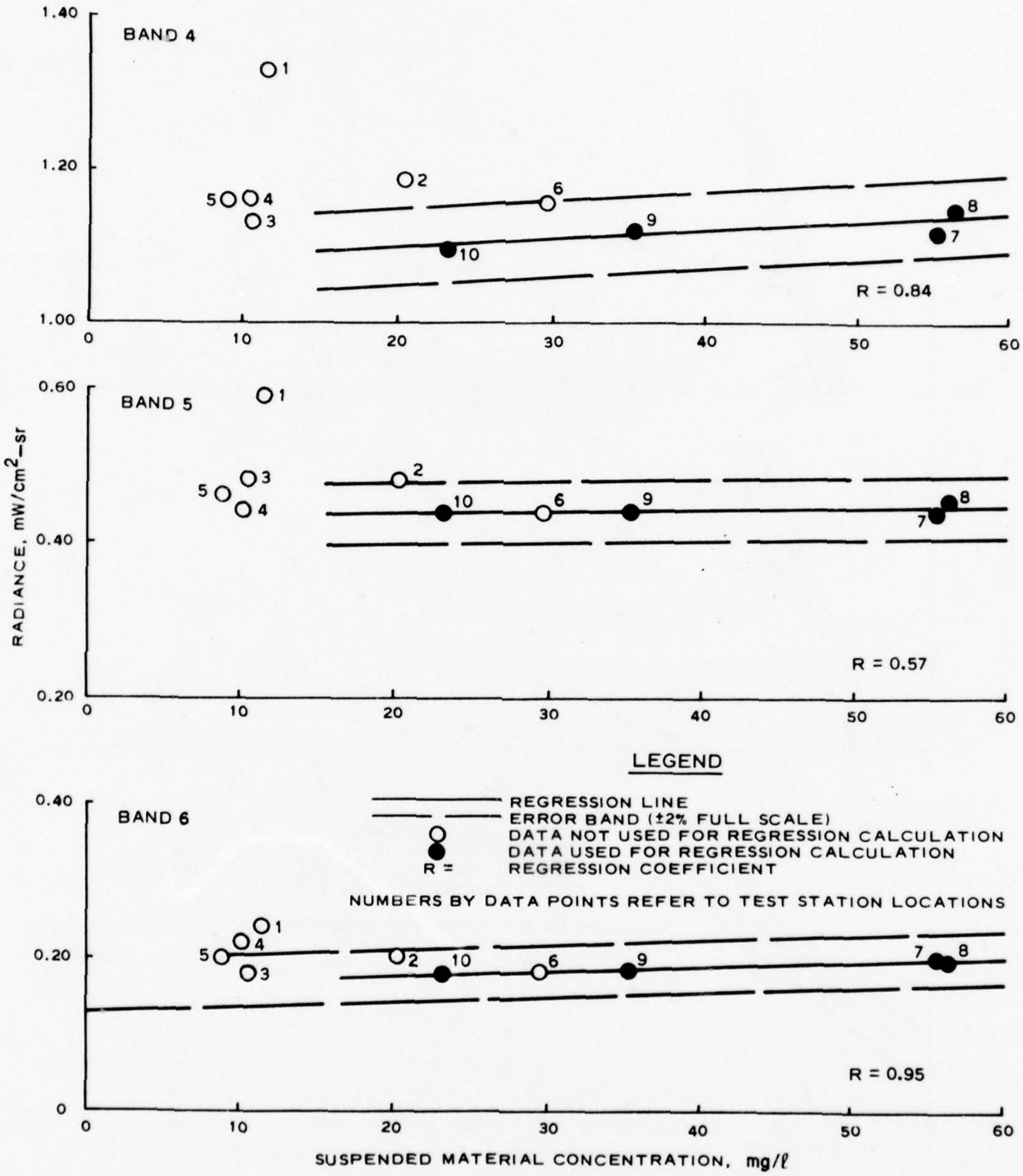


Figure 26. Radiance versus suspended material concentration Choptank River (population No. 2)

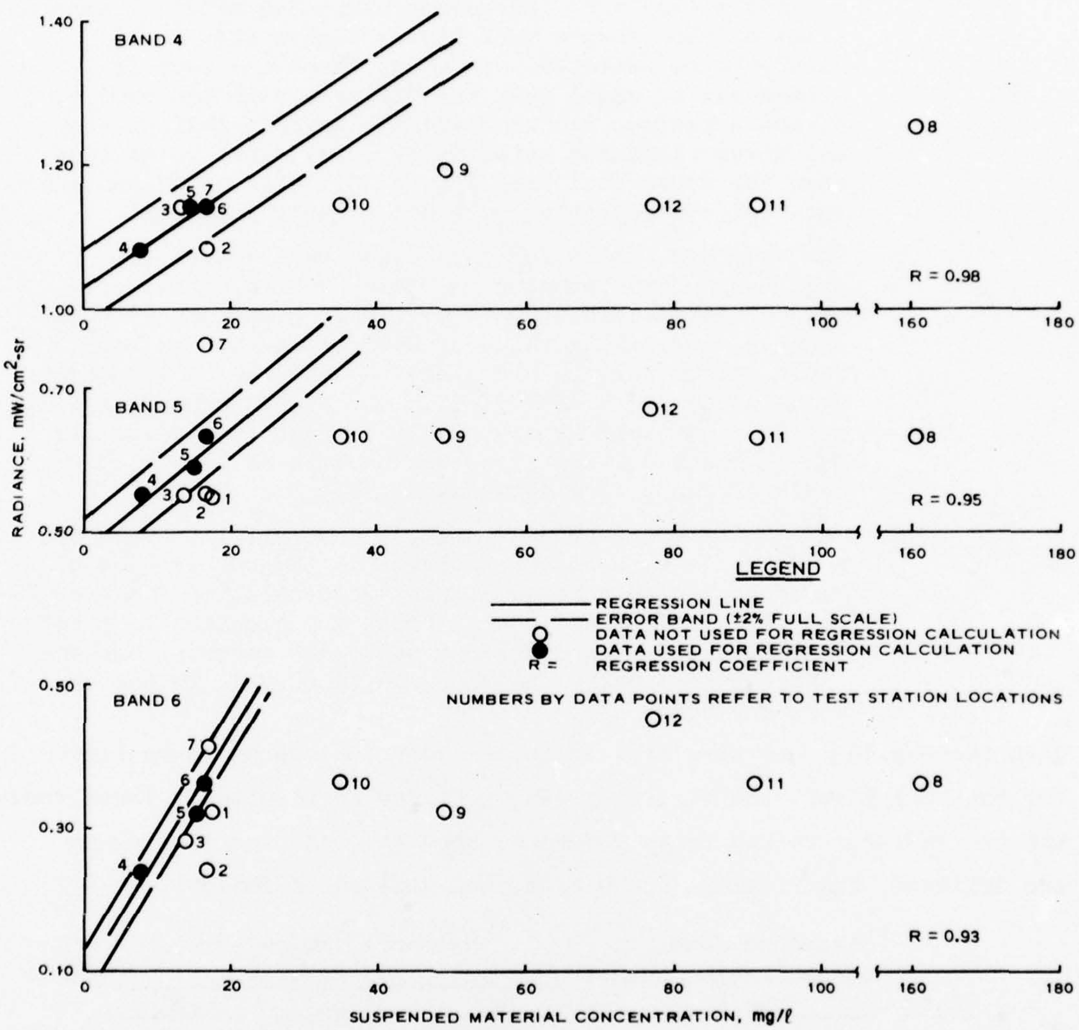


Figure 27. Radiance versus suspended material concentration, Chesapeake and Delaware Canal

of change of radiance values with concentration for the study area. For example, in cases where the band 4, 5, and 6 radiance values increased rapidly with increasing suspended material concentration (such as the Choptank River population 1, Figure 25), only two classes were selected. By contrast, when the radiance values increased slowly with increasing suspended material concentration (such as the York River, Figure 22), three classes were selected. In cases where the rate of increase was so small that the difference in the band 4, 5, and 6 minimum radiance and the maximum radiance for any given suspended material type was equal to or less than the error band (see Figure 26), classes of suspended material concentration were not clearly separable.

b. The radiance limits for each class were values (in mW/cm^2-sr) corresponding to whole numbers on the compressed data scale of 0 to 63 (Table 4, column 4). For example, a limiting value of 0.62 mW/cm^2-sr for band 5 would not be permissible since there is no corresponding value in column 4 of Table 4. On the other hand, a limit set at 0.59 would be acceptable because this value for band 5 has a corresponding value of 14 on the 0- to 63-scale of compressed data (column 4).

c. The limits on suspended material concentration were set to coincide with discontinuities in the correlation of radiance and suspended material concentration (Figures 22-27); and to include in each class any clusters of points that resulted when different suspended material concentrations had nearly the same radiance value in one or more MSS band.

When these guidelines were applied to the correlations shown in Figure 22 for the York River, the classes shown in Figure 28 resulted. Three spectra (hereafter referred to as reference spectra), one for each class, are defined. Numerically, the classes are defined as follows:

Class	Suspended Material Concentration Range mg/ℓ	Radiance, mW/cm^2-sr MSS Band 4	5	6
1	0-15	1.08-1.20 (19-21)	0.42-0.51 (10-12)	0.21-0.33 (5-8)
2	15-25	1.14-1.26 (20-22)	0.55-0.68 (13-16)	0.25-0.37 (6-9)
3	>25	1.20-1.31 (21-23)	0.72-0.80 (17-19)	0.33-0.41 (8-10)

Note: Numbers in parentheses are CCT values corresponding to radiance values shown.

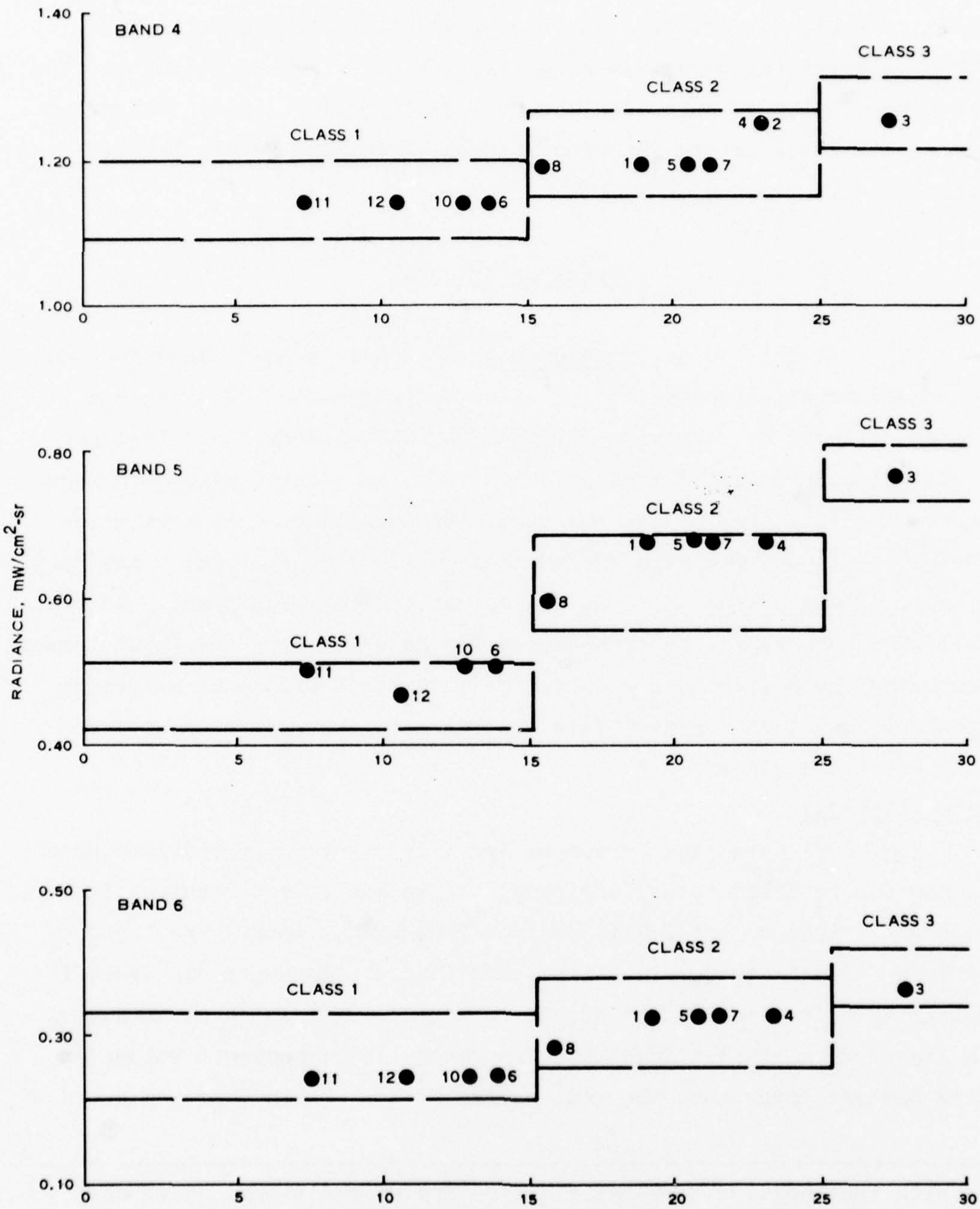


Figure 28. Radiance versus suspended material concentration, York River

111. Classes derived from the correlation curves for the other study areas (Figures 23-27) and their associated radiance values are given in Table 7. Two classes were originally established for the Wicomico River (Wicomico River, No. 1, Table 7). In an attempt to improve resolution of suspended material distribution, these classes were subsequently subdivided into four classes (Wicomico River, No. 2, Table 7).

Spectrum Matching

112. At this point, reference spectra have been defined for each suspended material concentration class for each material type, and pixel values defining 46.3-km-wide strips of an ERTS-1 scene have been recorded in compressed form on a set of four input tapes with each tape containing all data for one MSS band. By combining a pixel value on the band 4 input tape with corresponding values on the band 5 and band 6 tape, a reflectance spectrum can be defined for each pixel. In the following paragraphs, the procedures for interrogating the input tapes, comparing the reflectance spectrum of each pixel with each reference spectrum, and identifying pixels according to the reference spectrum they match are discussed.*

Data filtering

113. CCT data taken prior to April 1973 were characterized by a phenomenon referred to as "striping," since its effect resulted in horizontal stripes on the images derived from ERTS-1 data. The types of striping--radiometric, sixth-line, and intermittent--are discussed in detail in Reference 3. The effects of "striping" can be clearly seen in Figure 29a, row 6. Note that, in general, the radiance values on this row are lower than the rest of the field. On an image composed of

---

* With the addition of 9-track drives and an additional 8K of core memory, the process was modified so that the steps leading to picture tapes could be accomplished without the need to demultiplex the CCT's or record key tapes and output tapes. However, the processing technique was otherwise essentially unchanged.

COLUMN (OR PIXEL NUMBERS)

ROWS (OR SCAN LINES)	1	2	3	4	5	6
1	114	114	114	114	114	114
2	114	114	114	114	114	114
3	114	114	114	114	114	114
4	108	108	114	114	114	114
5	114	114	114	114	114	114
6	102	102	108	120	108	108
7	114	114	120	114	120	114
8	114	114	114	114	114	114
9	114	114	114	114	114	114
10	114	114	114	114	108	114

FILTER WINDOW

A. ORIGINAL ARRAY OF RADIANCE VALUES

COLUMN (OR PIXEL NUMBERS)

ROWS (OR SCAN LINES)	1	2	3	4	5	6
1	114	114	114	114	114	114
2	114	114	114	114	114	114
3	113	113	114	114	114	114
4	110	110	114	115	113	113
5	110	110	114	115	114	113
6	110	110	114	115	114	113
7	112	112	114	115	114	113
8	112	112	114	115	113	113
9	114	114	115	114	114	114
10	113	114	115	113	110	112

ROW IN WHICH STRIPE SHOWED CLEARLY IN ORIGINAL DATA ARRAY

B. FILTERED ARRAY OF RADIANCE VALUES

Figure 29. Digital filtering of radiance values

shades of gray, this row would show as a light-toned horizontal stripe. Such stripes are clearly anamolous, because no such linear features exist on the surface of the earth. Since the radiance values in such stripes are abnormal, the radiance spectrum derived from a pixel located in such a stripe will also be abnormal. When such values are used in a classification algorithm (see paragraph 115 below), the result will be an abnormal classification, and at best the stripes will be presented as lines of apparent suspended material concentrations either systematically higher or lower than the material on either side. At worst, the pixels will not fit a classification at all, and will show as stripes of a different population of materials.

114. To minimize the effects of striping on spectrum matching, the values on the digital tape were filtered digitally. The result can be seen by comparing Figure 29a and 29b. In Figure 29a, a filter "window" consisting of five pixels located in a column was taken as a basic element. The values of the five pixels were averaged, and the value of the average was substituted for the value of the middle pixel. Thus, in the example in Figure 29a, the value of the pixel in column 1, row 3, would be changed from 114 to 113. The five-pixel window was then moved incrementally along the scan lines. Upon completion of one horizontal pass, the window was dropped one scan line and the process repeated until the entire scene had been filtered. It should be noted that the original pixel values were always used in calculating the average values, <u>not</u> the substituted values. The result of this operation, as performed on the pixel array in Figure 29a is shown in Figure 29b. Note that the striping effect has been greatly reduced. The filtered data were then used in subsequent processes.

Generation of key tapes

115. The generation of key tapes begins with the radiance values and suspended materials concentration classes (Table 7). Using the band-4 radiance classes for the Rappahannock River as an example, the procedure is as follows. The band 4 suspended material concentration class limits (Table 7) were placed in computer memory as a table that contains the following information (Figure 30).

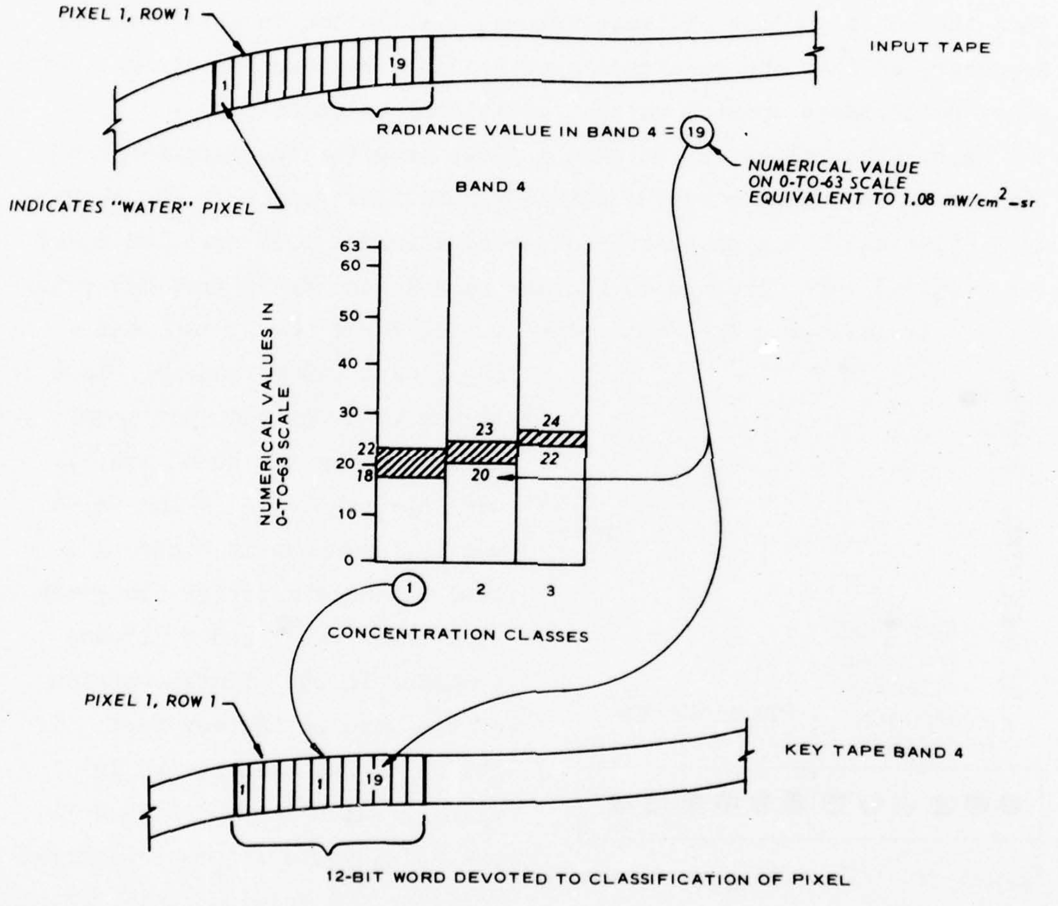


Figure 30. Input tapes converted to key tapes

Suspended Material Concentration Class	Radiance Minimum	Radiance Maximum
1	18	22
2	20	23
3	22	24

Note that values entered in the table are compressed data values rather than the corresponding radiance values. Tabulation in this form was necessary so that the reference spectra could be compared directly with pixel reflectance spectra without additional calculations.

116. The values on the band 4 input tape for the Rappahannock River site were then compared with the numerical ranges in the above tabulation and the appropriate suspended material concentration class (or classes) were recorded on the key tape in the space provided (Figure 31) as follows. The first pixel in the first row of the band 4 input tape (which contains in a 12-bit word the radiance level equivalent on a 0 to 63 scale) was interrogated. If the value was 19, as shown in Figure 30, the suspended material concentration class was 1 and a "1" was recorded in the alloted portion of the word on the key tape. If the value had been 20 (as in pixel 2 at the top of Figure 32), the value would fit the criteria for both suspended material classes 1 and 2. In this case, a "1" would be recorded twice in the portion of the key tape word alloted for suspended material concentration class designation. If the value had been less than 18 or greater than 24 (pixel 3, Figure 32), there would be _no_ match with a suspended material concentration class. Nothing would be recorded in the portion of the key tape word reserved for class designation, and the 12-bit word for the band 4 pixel value would contain only the pixel value and a "1" to

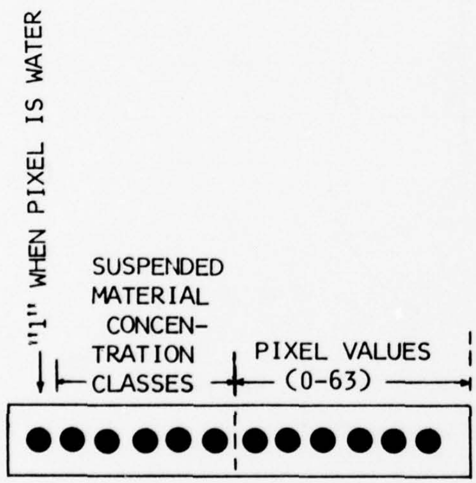


Figure 31. Key tape data format

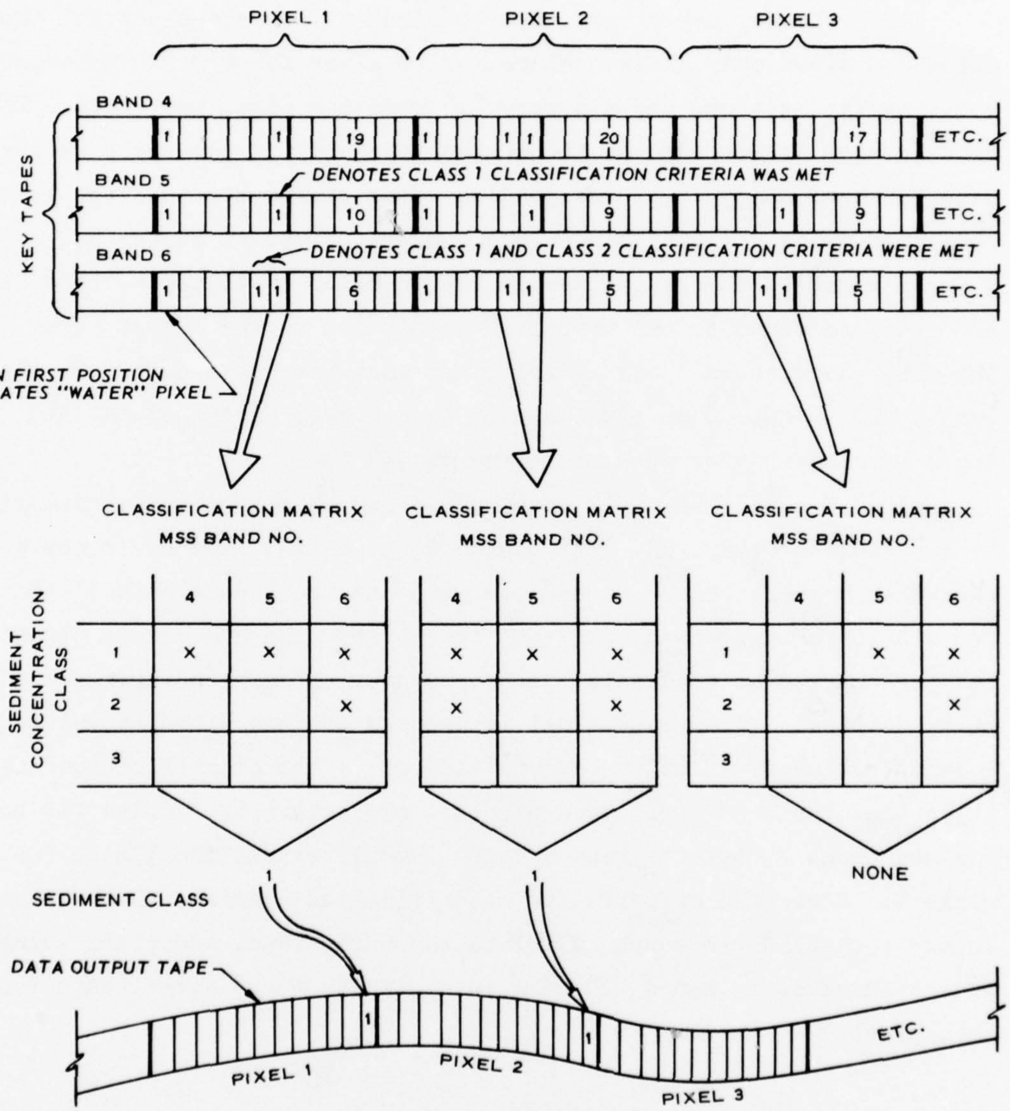


Figure 32. Generation of data output tape

indicate that this was a "water" pixel (Figure 31).

117. This process was repeated for each pixel on bands 4, 5, and 6 input tapes and resulted in a key tape for each band.

Generation of output tape

118. The key tapes were then combined to produce an output tape, which contained only class numbers, or no class numbers in the event no spectrum was matched, and a binary "1" when the pixel was water. The class number is recorded on the output tape only if the value on the key tape for band 4 and the corresponding value on the key tape for each of the other bands have the same class number. Thus, in Figure 32, since pixel 1 exhibits the same class number in bands 4, 5, and 6, the class number is recorded in the appropriate position on the output tape. On the other hand, even though pixel 3 has the same class number on the band-5 and -6 tapes, no class number is recorded on the output tape because no class number appears on the band-4 tape.

119. The results of this technique may be more clearly visualized by considering Figure 33. The radiance values and radiance numbers in parentheses describe the three reference spectra (from Table 7) that pertain to the Rappahannock River study area. The numbers in parentheses are entered as constants in the computer along with their associated class numbers. If a given pixel is assumed to have a band-4 value of 20, a band-5 value of 9, and a band-6 value of 5, the classification matrix shows that the band-4 and band-6 values are within the limits for both classes 1 and 2, but the band-5 value is only within the limits for class 1. Since the criteria for classification requires that the pixel values for all three bands fall into the same class, the pixel value is placed in class 1, and a "1" will be recorded on the output tape for that pixel.

Production of Photomaps

120. One form of computer output that was used for verifying correct operation of the computer program for recording output tapes was the computer map (Figure 34). This type of map is composed of line

	CLASS	SUSPENDED MATERIAL CONCENTRATION RANGE (mg/ℓ)	RADIANCE (mW/cm^2-sr) MSS BAND 4	5	6
SPECTRUM REFERENCE	1	0-15	1.03-1.26 (18-22)	0.38-0.55 (9-13)	0.12-0.25 (3-6)
	2	15-25	1.14-1.31 (20-23)	0.51-0.68 (12-16)	0.21-0.29 (5-7)
	3	25-30	1.26-1.37 (22-24)	0.59-0.72 (14-17)	0.25-0.33 (6-8)
PIXEL VALUE			1.14 (20)	0.38 (9)	0.20 (5)

CLASSIFICATION MATRIX
MSS BAND NO.

SEDIMENT CONCENTRATION CLASS	4	5	6
1	X	X	X
2	X		X
3			

Figure 33. Matrix for pixel classification for Rappahannock River

printer characters that denote the suspended material classes of individual pixels in the scene. In Figure 34, which covers a small portion of the Rappahannock River study area, the following class identifications are used:

a. Class 1 +

b. Class 2 -

c. Class 3 #

d. Unclassified 0

By referring to the digital map, band-4, -5, and -6 radiance values were found for the point enclosed in the small square. Interrogation of

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* Unclassified pixels are those water pixels with a reflectance spectrum that fails to match any one of the reference spectra; see Figure 32.

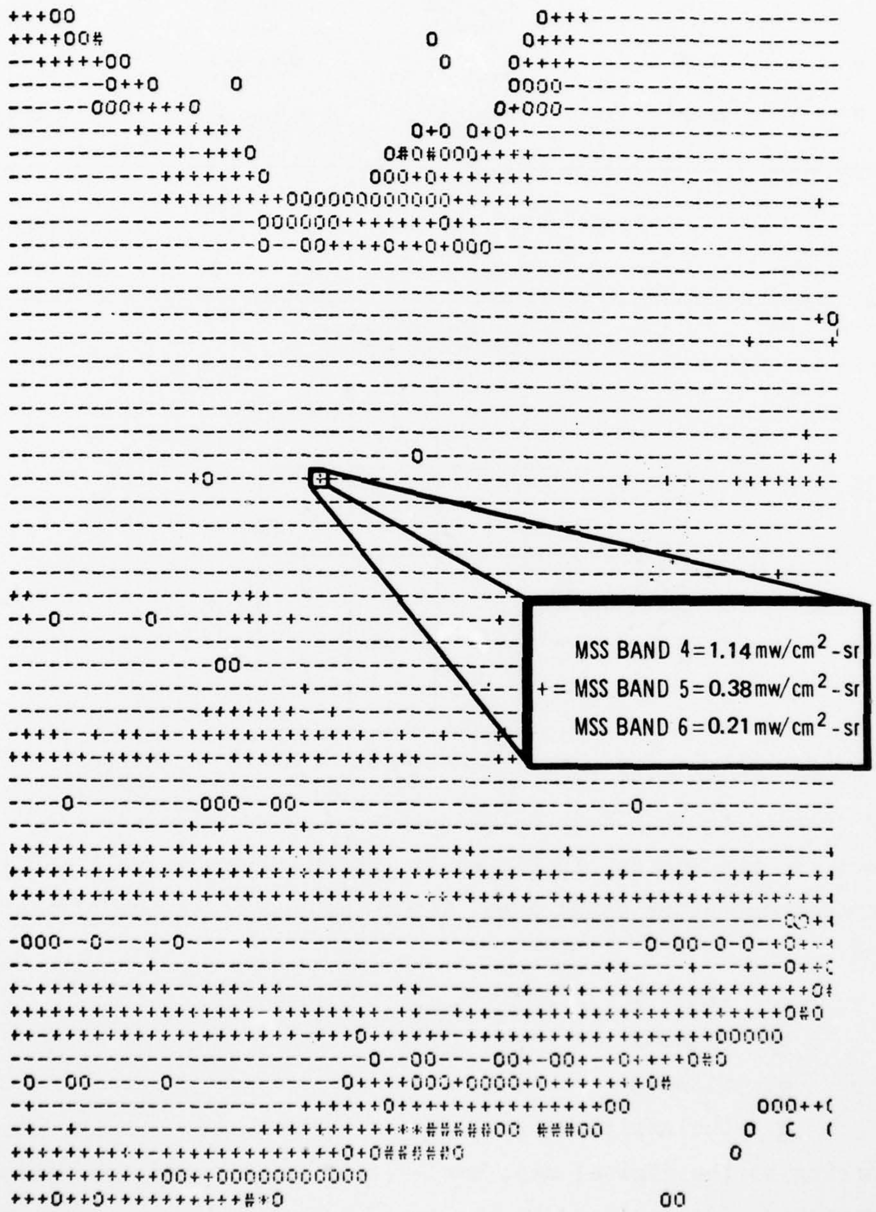

Figure 34. Example of computer map

these values (shown in the large box) should result in this pixel being assigned to class 1. Reference to the radiance values for the reference spectra given in Figure 33 indicates that the pixel should be class 1. A "+" appearing in the small square verifies proper computer program operation.

121. Since only one symbol per pixel is used in this output (as opposed to three symbols per pixel used in the maps produced on the line printer but showing radiance values, as in Figure 21), the WES line printer could accommodate rows (or scan lines) consisting of 52 pixels, as opposed to the rows of 20 pixels in the radiance maps (Figure 21). This results in a gratifying decrease in the overall size of the computer-produced map of a study area, but it is still far too large for convenience. The use of only one symbol per pixel also reduces, but does not completely eliminate, geometric distortions. Thus, even if the map was reduced to convenient size by a method such as photographic reduction, the resulting map would still be inconvenient to use.

122. In view of this, it was decided to use the data output tapes and a film reader/writer (Figure 35) to produce photomaps of the study areas, in which the suspended material concentration classes would be shown in shades of gray, land areas would be black, and unclassified water areas would be white.

Film reader/writer

123. The film reader/writer is an electromechanical photograph scanning and writing system designed to accommodate photographs up to 22.9 cm by 22.9 cm in size. The instrument can operate in either of two modes--an input or scanning mode, or an output or writing mode. The writing mode was used to make suspended material distribution photomaps. For this mode of operation, the instrument is equipped with a rotating drum and an optical system consisting of a light-emitting diode (LED), a selectable aperture, and a lens system that focuses a spot of light from the LED onto the perimeter of the drum. The drum is in a light-tight enclosure, which can be demounted and removed to a photographic darkroom for loading and unloading film. A piece of film is clamped to the outside of the drum. As the drum rotates, the light

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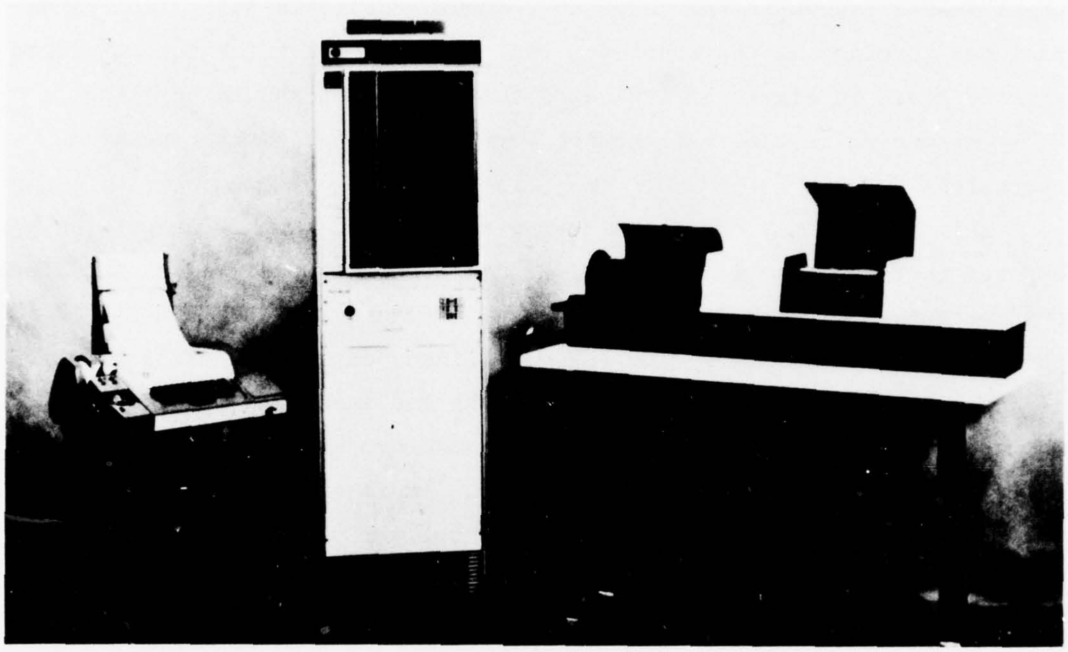

Figure 35. Film reader/writer

intensity of the LED can be modulated incrementally through a range from 0 to 255 inclusive. However, no single film is capable of differentiating among so many levels of light intensity, and thus a optimum film for the purpose must be selected. The film chosen was Kodak Linagraph Shellburst film, Type 2474. The use of this film in the film writer yields only 64 repeatable levels of gray, as measured with an optical densitometer.

124. The film can be exposed at 12.5-, 25.0-, or 50.0-μm raster intervals (selectable) along the circumference of the drum. As the drum rotates, the carriage supporting the optical system is stepped incrementally in the axial direction at the selected raster interval until the total area of the film or the area of interest has been exposed. The use of high-speed film permits very short exposure times and results in a recording rate of up to 60,000 points per second.

125. The entire operation of the instrument is under the control of a minicomputer so that real-time manipulation of the digitized density data can be used to produce a number of photographic effects. For

example, magnification of an original negative can be achieved by scanning a negative at one raster in the reading mode and writing a new film at a larger raster. The number of gray levels can be reduced from 64 to 32, 16, 8, 4, or 2 to enhance an original negative visually or to provide isodensity contours. Level slicing (that is, the extraction of one particular gray level) is also possible, and the location of pixels can be changed by judicious computer programming.

Density control and
gray level selection

126. The ability to select shades of gray that will be assigned to suspended material concentration classes is a necessary prerequisite of producing photomaps. However, to achieve this ability, very careful control over the photographic process and knowledge of the relation between the digital input and the photographic output of the film writer are required.

127. Control of the photographic process was achieved in the following manner. Prior to use, the film was stored at approximately 0°C to minimize shift in speed and color sensitivity. Immediately following exposure, the film was developed to minimize latent image shift. Exposed film was developed for 8 min. in D-19 developer at a temperature of 20° ± 0.28°C.

128. To establish the relation between digital tape input (that is, between the 255 light intensity levels through which the light-emitting diode can be modulated) to the film writer and the 64 possible gray shades on exposed film, a computer tape was written that contained a set of 21 values between 0 and 255 (see second column in Table 8). It was hoped this would result in a gray step wedge on film with density steps of approximately 0.15 (third column in Table 8). A film was then "written" using this tape as input. The film was developed, and the optical density of each step was measured with a W. M. Welch Co., Model 3853J Densichron. The resulting measured density values are given in the fourth column in Table 8. A graph of the results is shown in Figure 36. The film density (fourth column in Table 8) is distributed over the range of 0.07 to 2.42. This range can be expected to change

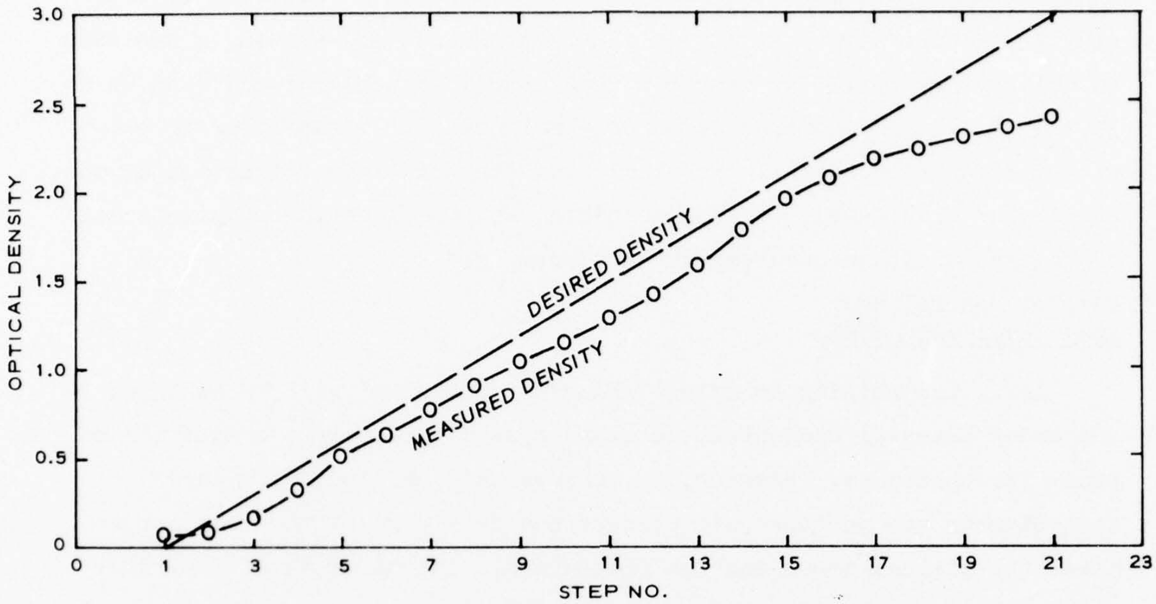

Figure 36. Optical density versus step number

as a function of film age, film development time, etc.

129. Figure 36 shows that the relation between optical density and computer tape value (step number) is almost linear between step 3 and step 16 and suggests that differentiation of suspended material concentration classes in photomaps can be accomplished by selecting computer tape values anywhere within these limits. Unfortunately, these limits are substantially reduced when the image produced on photographic film is to be used to print a photomap on photographic paper as was intended in this study. Experience at WES showed that the usable film density range (0.17 to 2.07) was reduced by the responses of the photographic paper to a range of approximately 0.33 to 1.79 (step 4 to step 14 on Table 8)--this range varying somewhat with paper age, development procedures, etc. As a result, density values (gray shades) between 0.49 and 1.68 (computer tape values between 42 and 143) were used to obtain maximum contrast between suspended material concentration classes. At the same time this allowed for vagaries of the photographic material and process. In addition, values were as widely spaced within these limits as the number of classes would permit. For example, three

classes of suspended material concentrations were used for the Rappahannock River study area. To depict these three classes on a photomap, the following computer tape values were selected:

a. Class 1 143

b. Class 2 92

c. Class 3 42

This selection resulted in areas with the lowest sediment concentrations having the highest gray level on the photographic film produced by the film writer. But, it also resulted in these areas having the lightest gray level on the photomap. Similarly, since land areas were to be black and unclassified areas were to be white on the photomap, "000" was selected for land and "255" was selected for unclassified areas.

Preparation of picture tapes

130. After the shades of gray were selected, a new tape (picture tape) was recorded. In the process of recording the picture tape, each suspended material concentration class number on the output tape was converted to its corresponding computer tape value and the gray level value was recorded on the picture tape. In addition, corrections were made for pixel size and skew.

131. Pixel size correction. An ERTS-1 pixel has a width-to-length ratio of approximately 1:1.38. The film writer, on the other hand, exposes only square pixels on film. To correct for this discrepancy, the pixel values of every third and every twentieth scan line were duplicated on the film (Figure 37).

132. Skew correction. The skew phenomena occurs because approximately 25 sec are required for ERTS-1 to traverse from the north extremity to the south extremity of a scene. During this time the rotation of the earth carries the surface eastward 11.49 km at the latitude of Chesapeake Bay. This means that the surface moves eastward with respect to the satellite orbital path one pixel width (57 m) in 0.124 sec. Thus, in the time that it takes the surface to move eastward the width of one pixel, the satellite moves southward along its orbit about 11.6 scan lines. This systematic error can be readily corrected to the accuracy required in this study by offsetting each successive group of 12 scan

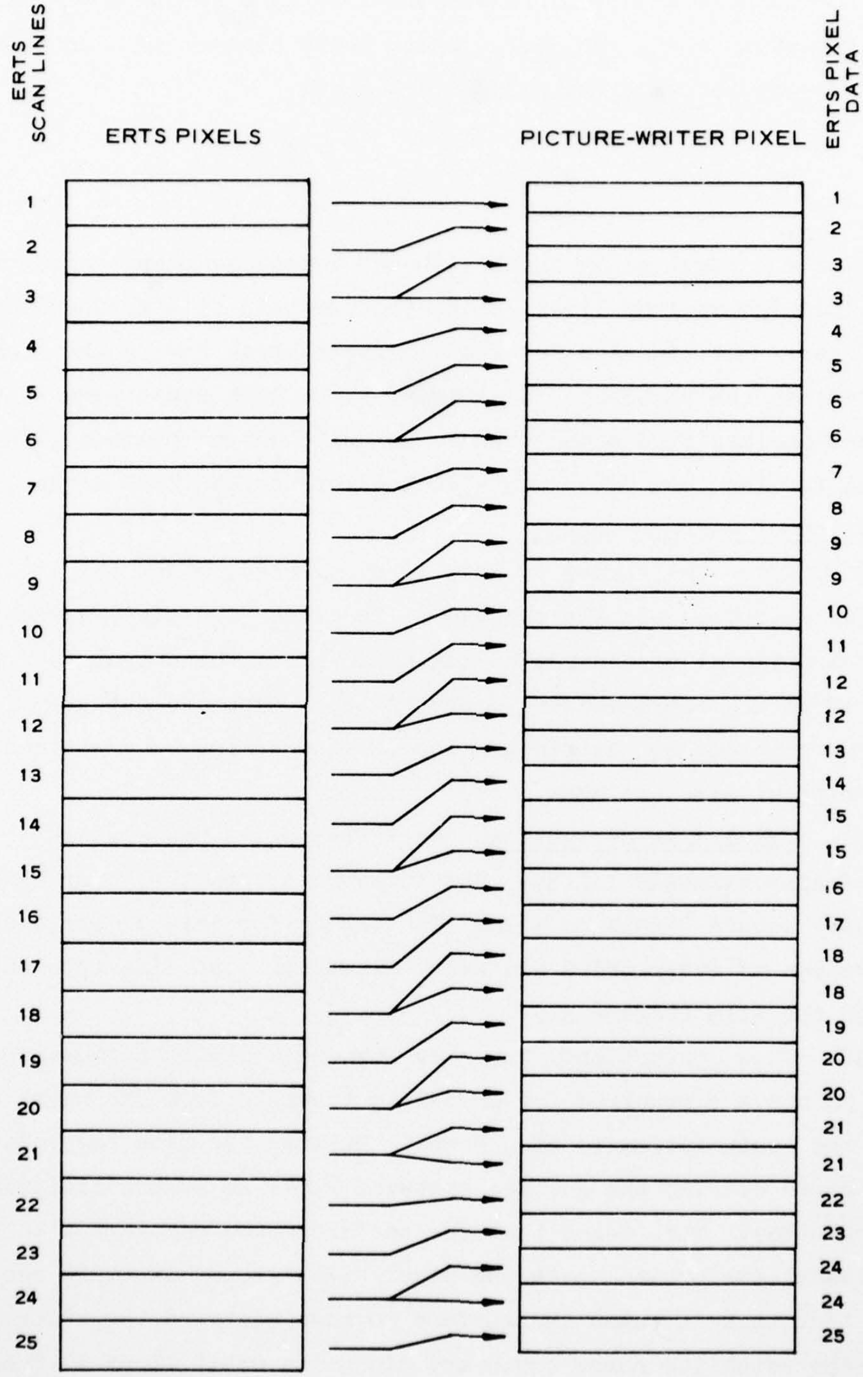

Figure 37. Method of bringing film-writer pixel array into accord with ERTS-1 pixel array

lines to the westward by one pixel width, as illustrated in Figure 38. An appropriate number of false pixels was inserted at the beginning of each scan line to bring the digital array back into a rectangular array, thus simplifying the picture-writing process. The result is only barely perceptible on the resulting film because of the small pixel size, but is nevertheless effective in correcting for skew.

Photomap production

133. Picture tapes were used to expose photographic film with the film writer. The film was developed using the same procedures used for developing the gray level step wedge. Conventional photographic printing and enlarging techniques were then used to produce the photomaps.

Presentation of Photomaps

134. Photomaps of the five study areas are presented in Figures 39-48. Two photomaps cover the York and Rappahannock Rivers, and the C&D Canal study areas (Figures 39-40, 43-44, and 47-48, respectively). This results from the data from more than one CCT being required to cover these areas. However, in each case the same class limits were used to produce both photomaps. Figures 41 and 42 are photomaps of the Wicomico River study area. The class limits used to produce the photomap in Figure 42 were subdivisions of the class limits used to produce the photomap in Figure 41. Figures 45 and 46 show two different populations established from the correlation of radiance and suspended material concentration for the Choptank River. Figure 47 shows the C&D Canal as a narrow interrupted line extending to the northeast (right) extremity of the figure. Figure 48 shows the remainder of the C&D Canal as a narrow interrupted line that enters the figure from the southwest (lower-left) portion of the photomap.

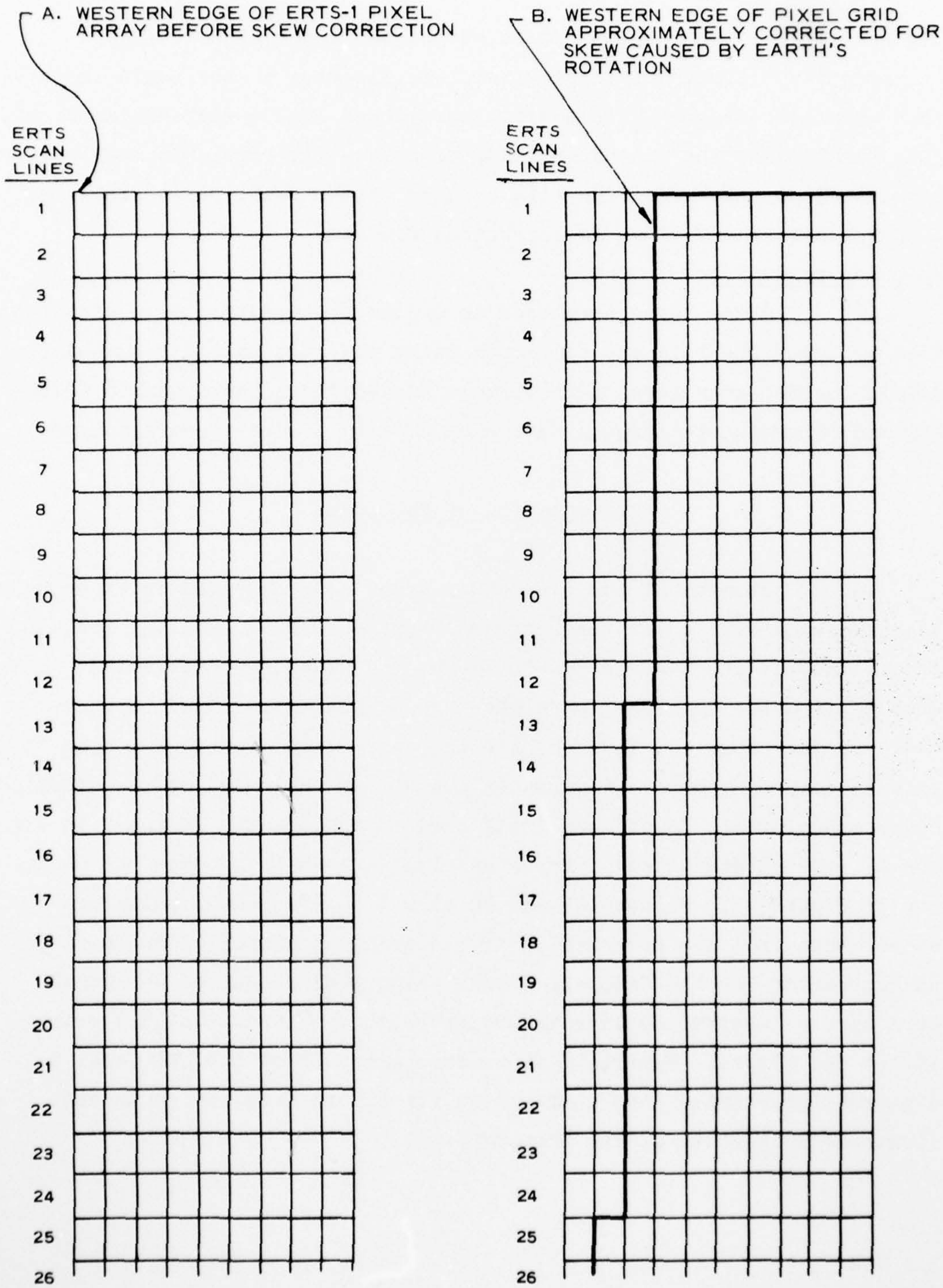

Figure 38. ERTS-1 pixel array approximately corrected for effects caused by earth's rotation

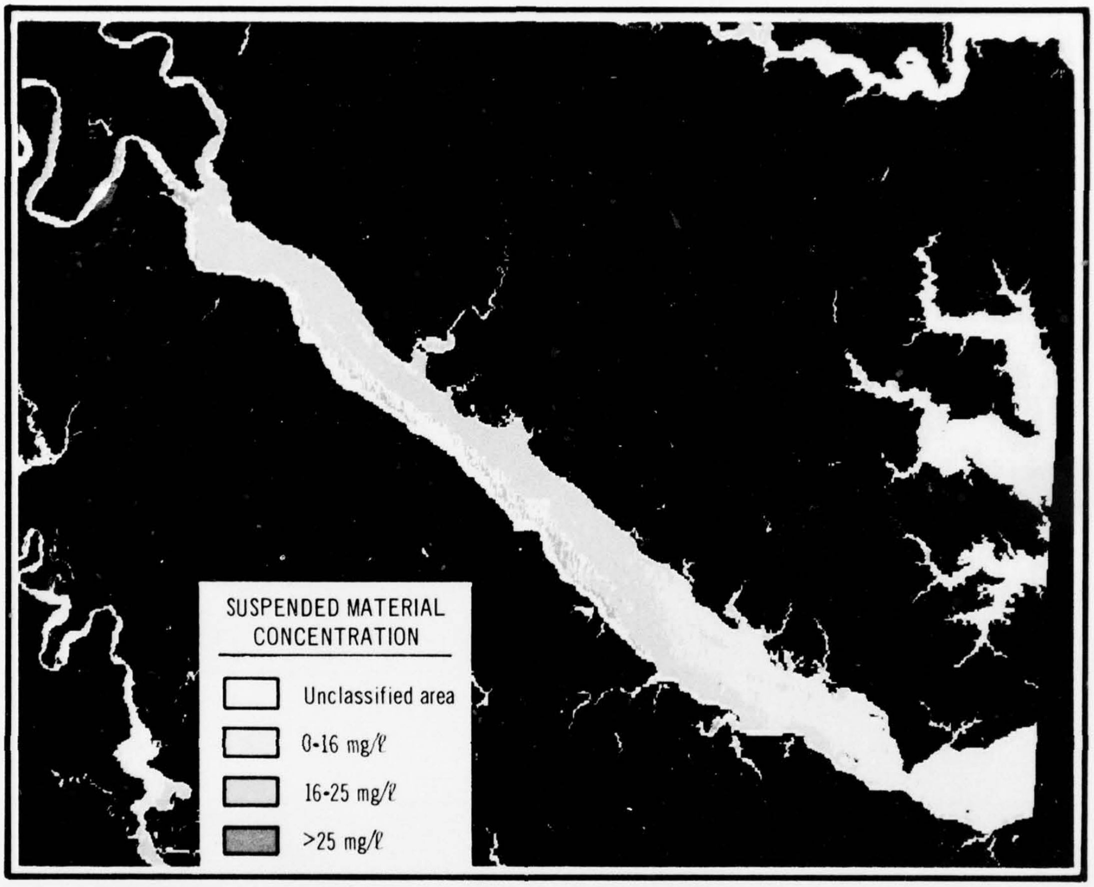

Figure 39. Suspended material distribution photomap, York River

Figure 40. Suspended material distribution photomap, Chesapeake Bay in the vicinity of the York River

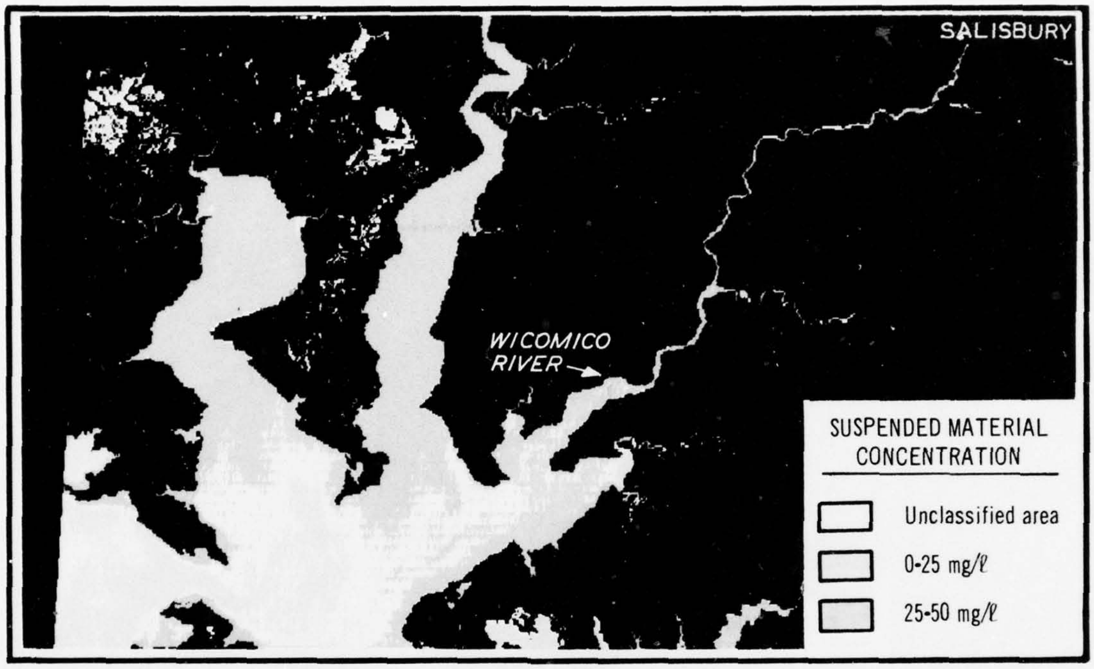

Figure 41. Suspended material distribution photomap, Wicomico River and vicinity (No. 1)

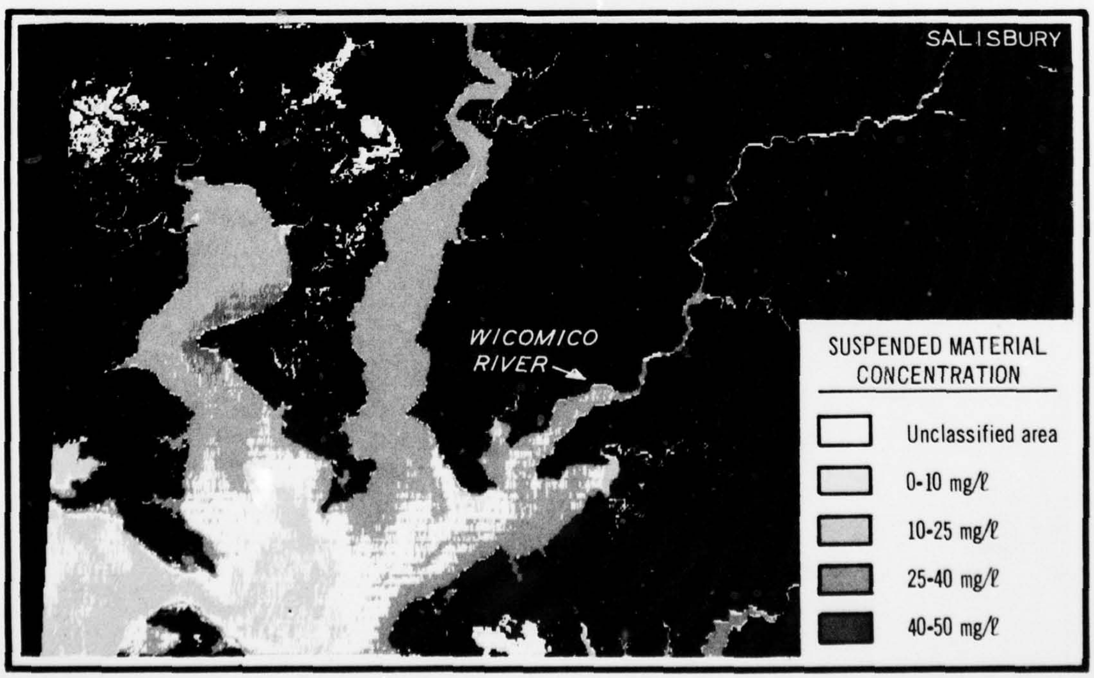

Figure 42. Suspended material distribution photomap, Wicomico River and vicinity (No. 2)

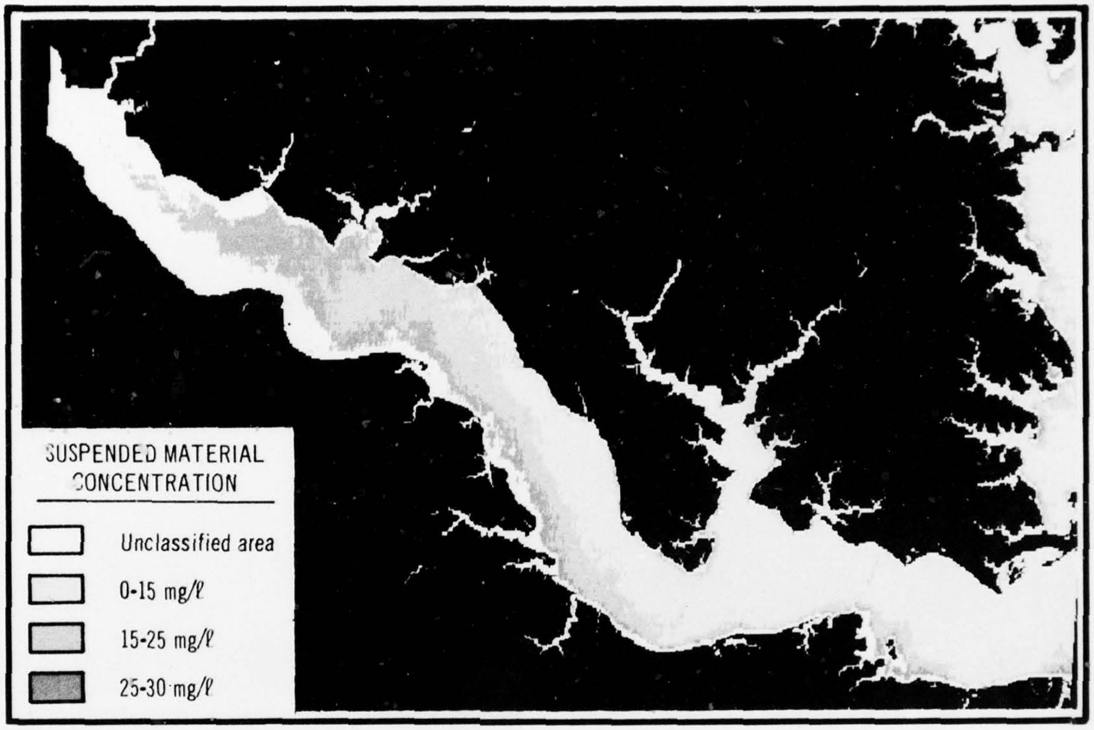

Figure 43. Suspended material distribution photomap, Rappahannock River

Figure 44. Suspended material distribution photomap, Chesapeake Bay in vicinity of the Rappahannock River

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MOVEMENT OF SUSPENDED PARTICLES AND SOLUTE CONCENTRATIONS WITH --ETC(U)
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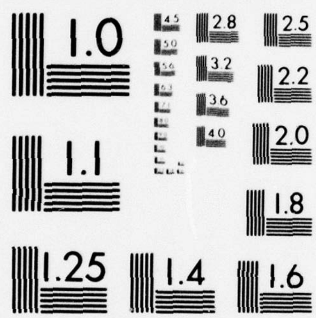

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

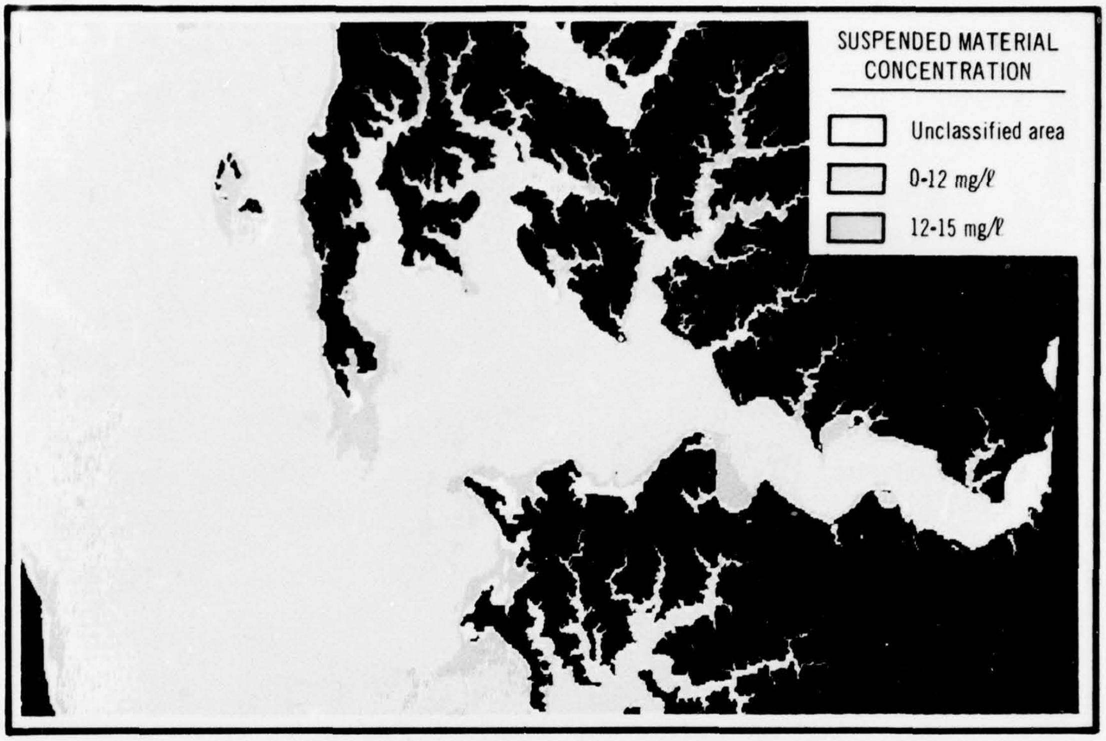

Figure 45. Suspended material distribution photomap, Choptank River and vicinity (population No. 1)

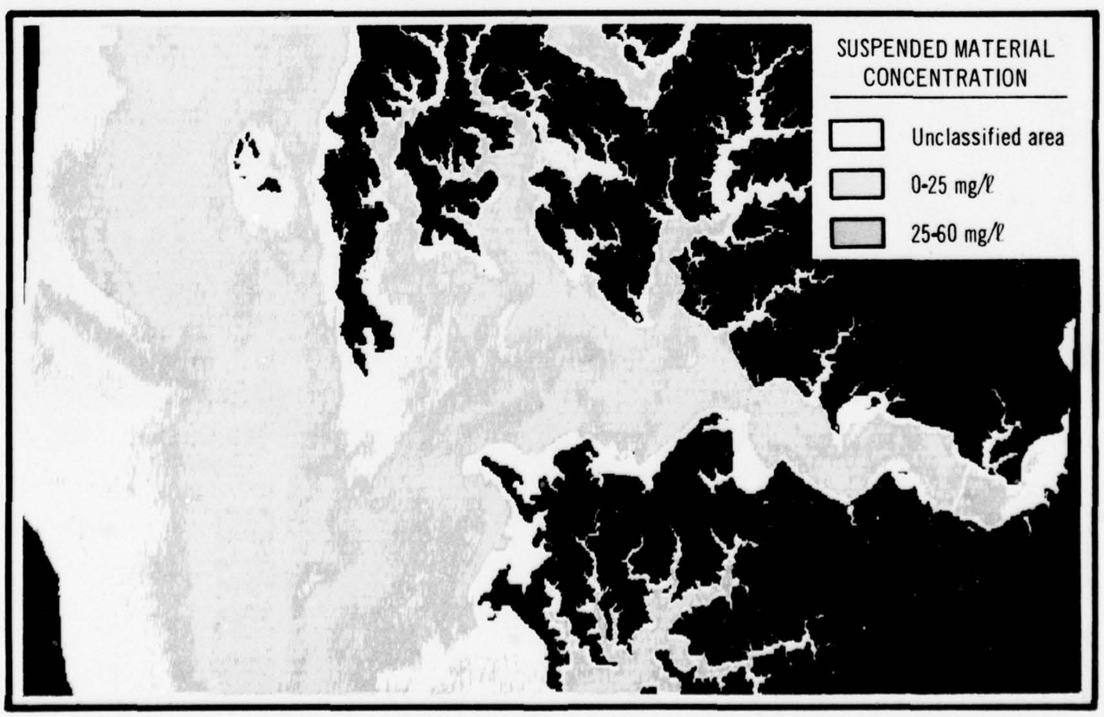

Figure 46. Suspended material distribution photomap, Choptank River and vicinity (population No. 2)

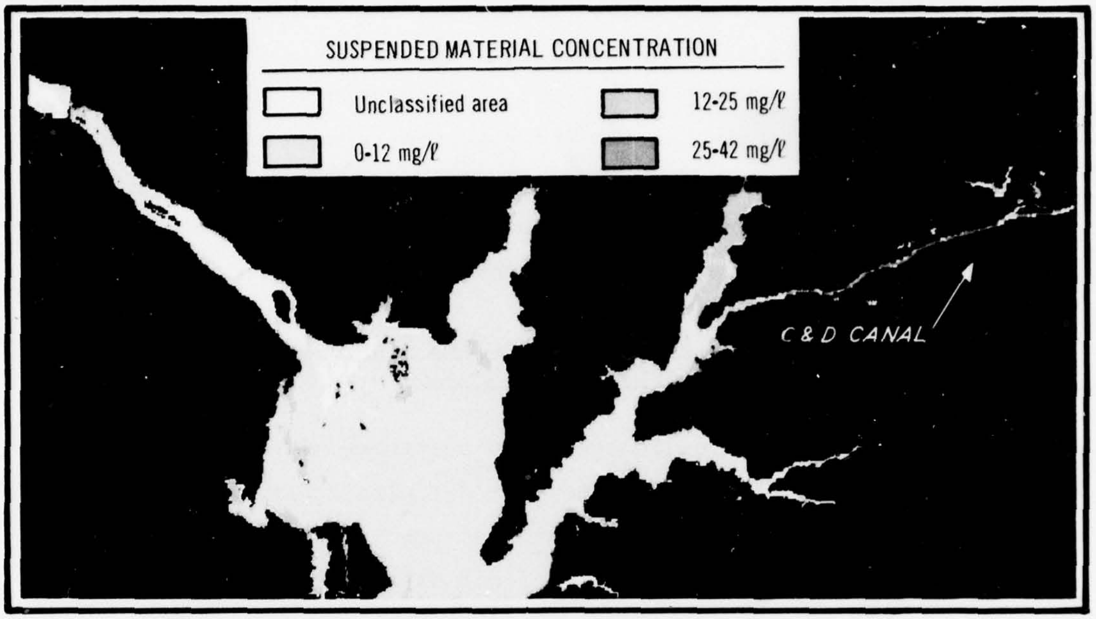

Figure 47. Suspended material distribution photomap, Chesapeake and Delaware Canal with Elk River and portion of the Chesapeake Bay and Susquehanna River

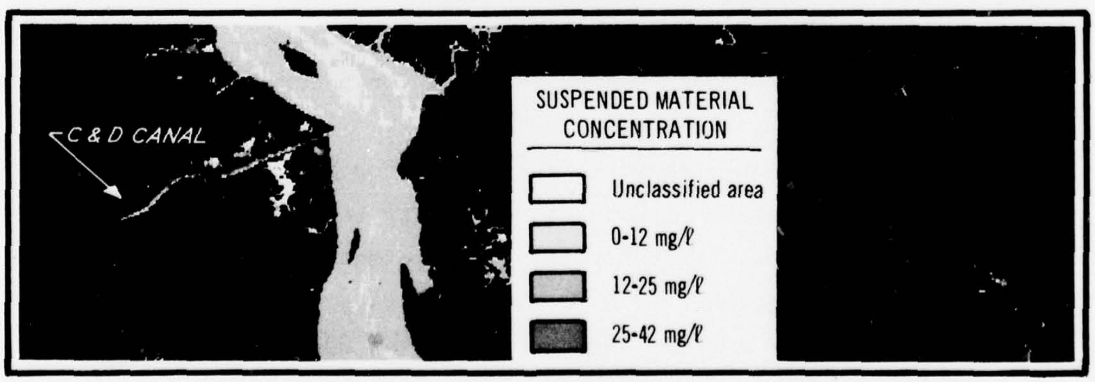

Figure 48. Suspended material distribution photomap, Chesapeake and Delaware Canal and portion of Delaware Bay

PART V: RESULTS OF STUDY

135. In the preceeding portions of this report, techniques are presented for interrogating ERTS-1 CCT's, converting the CCT data to radiance values, establishing the correlations between radiance and suspended material concentration, and producing photomaps that show the distribution of different concentrations of materials. Photomaps are presented for each of the five study areas.

Correlation of Radiance and Suspended Material Concentration

136. The graphs of radiance versus suspended material concentration (Figures 22-27) indicate there is a definite correlation between the radiance measured by each MSS band and the quantity of material being transported in suspension. "Accepted" data were analyzed by linear regression of radiance versus suspended material concentration and produced regression coefficients greater than 0.57 in all cases and greater than 0.90 in 12 of 16 correlations. A regression line was then drawn through these points and the regression line was bounded on each side by an error band. The result was a straight line correlation showing an increase in the radiance in each MSS band for a corresponding increase in suspended material concentration.

137. Reference spectra were established for the correlations between spectral reflectance (radiance values for bands 4-6) and suspended material concentration. As a result of the potential error introduced by instrumental variations ($\pm$2.0 percent) and the inevitable sampling errors, the reference spectra were defined by an upper and lower radiance limit rather than a single value for each band. A degree of engineering judgment was required to arrive at these limits. This is particularly true in selecting the number of classes (ranges) to be used. For example, selecting four classes rather than two has a preponderant effect on the clarity of the separation of classes in the photomap, but in no way alters the basic relation between radiance and suspended material concentration.

Differentiation of Material Types

138. The capability to differentiate among types of materials requires that the materials have detectable differences in spectral reflectance characteristics. For example, as previously noted (paragraphs 37 and 41), the dominant agricultural soils of the York River drainage basin are reddish, and those of the Rappahannock River basin are predominantly brown. Therefore, band-4 radiance should be lower in the York River than in the Rappahannock, and the band-5 and -6 radiance values should be higher for the York than those for the Rappahannock.

139. When the correlation bands of the York River (Figure 22) and Rappahannock River (Figure 24) are superimposed, as in Figure 49, it will be noted that in general these expectations are realized. However,

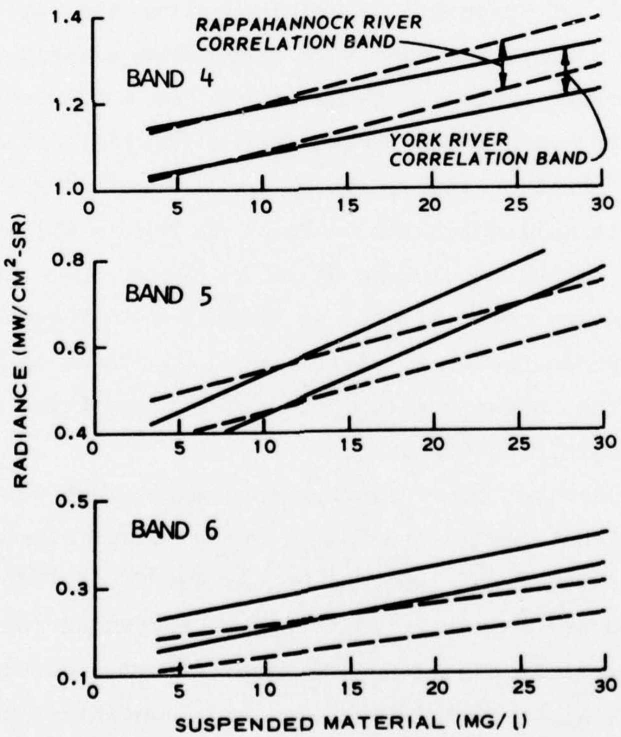

Figure 49. Comparison of correlation of radiance versus suspended material concentration for York and Rappahannock Rivers

the relation is clear only at suspended material concentrations above about 15 mg/ℓ. Below concentrations of 15 mg/ℓ the correlation bands overlap so completely that discrimination is impossible. In the range from 15 to 25 mg/ℓ, band 6 provides suitable discrimination, and above 25 mg/ℓ both bands 5 and 6 provide discrimination. Thus, it is clearly possible to differentiate between water masses containing the two types of suspended materials, provided the concentrations are above about 15 mg/ℓ.

140. The Choptank River data provide a more difficult and more confusing problem. A first look at the basic data (Figures 25 and 26) suggests that there is no relation between suspended material concentration and radiance, because (with perhaps the exception of station 1) the data points seem to be distributed essentially along horizontal trend lines. The indication is that the radiance values are the same regardless of the amount of suspended material--a situation that might possibly exist if, in fact, all data were taken from a mixing zone in which a variety of material types are found in various concentrations.

141. However, when a deliberate search is made for data points that trend along straight lines, two groups emerge, namely stations 1, 4, and 5 (which is called population No. 1 in Figure 25) and 7, 8, 9, and 10 (which is called population No. 2 in Figure 26). These sets yield high regression coefficients, as indicated in Figures 25 and 26. However, the suspended material distribution photomaps in Figures 45 and 46 indicate that these populations coexist everywhere in the estuary--an impossible condition.

142. There are yet other reasons to suspect that the relations obtained are at least partly spurious. One of these reasons revolves around the calculated trend lines of population No. 1 (Figure 25). If these trend lines are extrapolated to higher suspended materials concentrations (an admittedly dangerous and uncertain procedure), band 4 will exceed the sensor limit (2.48 mW/cm^2-sr) at a concentration value of about 18.4 mg/ℓ. Similarly, band 5 will exceed the sensor limit (2.00 mW/cm^2-sr) at about 80.96 mg/ℓ. The implication is that water containing this material in suspension would reflect so much energy in bands 4

and 5 that the sensor would be saturated at material concentrations of less than 30 mg/ℓ. It is difficult to imagine a material with such properties; certainly none has been noted in Chesapeake Bay.

143. Considering the locations of the data collection stations (Figure 10), it seemed reasonable to subdivide the data points into two populations; namely, those in the Choptank River channel (stations 6, 7, 8, 9, and 10), and those in the outer Choptank estuary (stations 1, 2, 3, 4, and 5). When regression lines were calculated for these two populations, the results are as illustrated in Figure 50. Note that almost complete discrimination is provided by bands 4 and 5 above concentrations of about 45 mg/ℓ; and band 4 provides discrimination at concentrations above 30 mg/ℓ (assuming that the regression lines for population 1 can be extrapolated so far beyond the limits of the data). Below that value, however, confusion is more or less complete, although there is some tendency for population 1 radiance values to be higher in all bands at equivalent materials concentration values.

144. If the original interpretation is still assumed to be correct (the relations expressed in Figures 25 and 26), then a somewhat different approach might be possible. If the correlation bands for Choptank River populations 1 (Figure 25) and 2 (Figure 26) are superposed as in Figure 51, a distinction can be made between population 1, at concentrations above about 12 mg/ℓ and below about 9 mg/ℓ, and population two. A zone of uncertainty exists where population 2 is present in concentrations between about 9 and 12 mg/ℓ. Assuming the zone of uncertainty to be a mixing zone and acknowledging that some inaccuracies would be inherent in the process, an attempt was made to produce a photomap showing the location of the mixing zone. To produce this photomap, the following classes were established:

		Radiance, mW/cm^2-sr MSS Bands		
Class	Description	4	5	6
1	Population 1 (12-15 mg/ℓ)	1.20-1.43 (21-25)	0.51-0.72 (12-17)	0.21-0.37 (5-9)

(Continued)

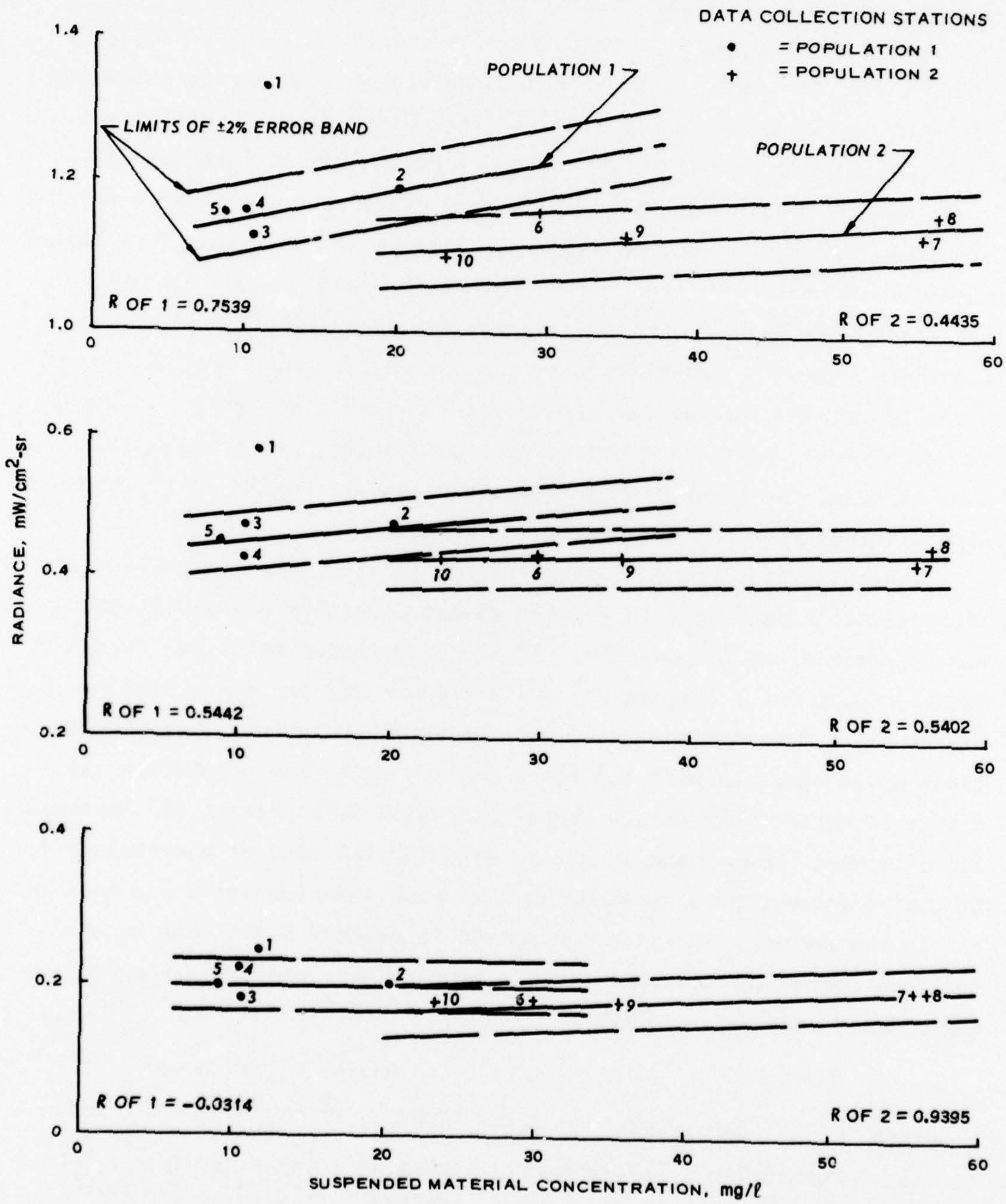

Figure 50. Possible suspended materials populations in the Choptank River study area

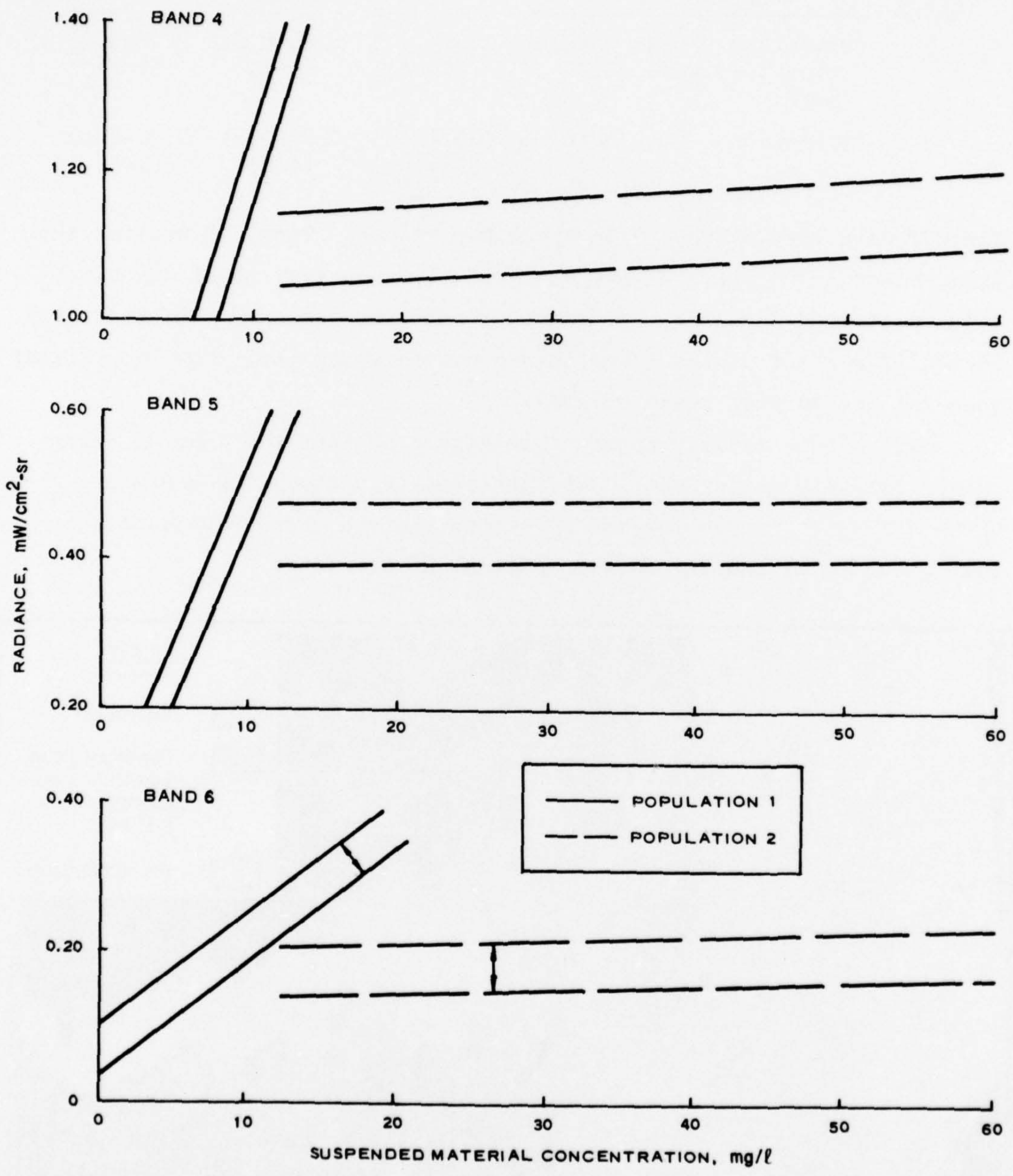

Figure 51. Comparison of correlation of radiance versus suspended material concentration for Choptank River

Class	Description	Radiance, mW/cm^2-sr MSS Bands 4	5	6
2	Population 2 plus population 1 between 9-12 mg/ℓ	1.08-1.26 (19-22)	0.38-0.51 (9-12)	0.16-0.25 (4-6)
3	Population 1 (0-9 mg/ℓ)	0.97-1.03 (17-18)	0.25-0.34 (6-8)	0.04-0.16 (1-4)

The CCT data were matched with the above values. Then, in writing the film, class 1 and class 3 were assigned the same gray level and class 2, which contained data for the "mixing zone," was assigned a lighter gray level. The print of the image thus produced would then show the "mixing zone" as the darkest shade of gray.

145. It is readily apparent in Figure 52 that the zone of uncertainty is not a mixing zone, but rather a strip along the shoreline where the water is shallow and a few other areas where wave action or some other local anomaly caused spectral uncertainty.

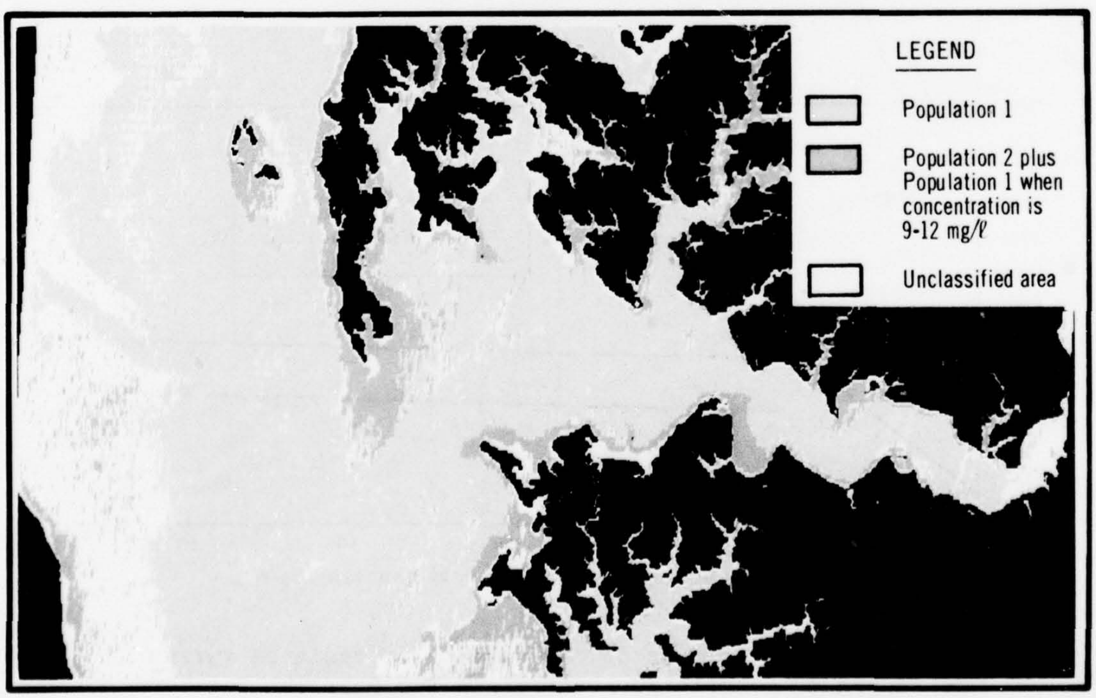

Figure 52. Photomap of Choptank River constructed on the basis of two suspended material types (Figures 26 and 27)

Causes of classification and correlation difficulties

146. As previously discussed (paragraphs 106 through 108), an examination of the probable circumstances at the time of the ERTS-1 overpass was made of all suspect data collection stations. While the conclusions are uncertain, they do indicate the kinds of things that can confuse the issue. Some examples are discussed below.

147. York River data collection station 2. This station was near a bridge crossing the river at West Point, Virginia. It is possible that the bridge cast a shadow on the station at the time of the satellite overpass. However, if this had been the case, the radiance values would be expected to be abnormally low, when in fact they are abnormally high. The high radiance values preclude the possibility of shadow interference being the reason for pixel anomalies. The water quality data reveal a very low salinity (1.7 ppt), which suggests inflow near this point of a material unlike that found in the other areas. This may be material from the paper mill located in the vicinity of West Point, in which case station 2 would be expected to be spectrally different from the other areas. Finally, the river is quite narrow at this point, and it is possible that secondary reflection from the banks contaminated the radiation.

148. York River data collection station 9. This station may have been inadvertently located at a point along the river where the water was shallow. Bathymetric charts show that at some points in this vicinity the water is less than 2-m deep.

149. Problems associated with water depth may be a major cause of failure to fit many pixels into the classifications. A graphic example of this effect can be seen in Figures 41, 45, 47, and 49. Each of these figures is characterized by a white (unclassified) boundary around all or portions of the water body separating land from water. Water depth in these zones is known to be approximately 2 m or less. To be sure, the same effect might in some places be caused by suspended materials entrained by wave action. This is unlikely in sheltered coves, however, and the effect occurs in coves as well as on the exposed shores.

150. York River data collection station 13. This station, which is east of Gloucester Point, may be strongly influenced by waters from the open bay. There is some indication that the outflowing river water clings to the south shore of the outer estuary, implying that station 13 might be occupied by bay water containing lower concentrations of suspended material.

151. Wicomico River data collection station 1. This station was located in the vicinity of the poultry processing plant near Salisbury, Maryland. The radiance values for this point (Figure 23) are far outside the error band, indicating that this area contains water with spectral characteristics altogether different from the surrounding waters.

Questions of validity

152. The validity of the technique for establishing correlations between radiance and material concentration may be questioned on the basis that concentrations in this study seldom exceeded 60 mg/ℓ. Only one site in the Wicomico River and three sites near the Delaware Bay entrance to the C&D Canal had concentrations higher than 60 mg/ℓ. A subsequent study to validate the procedure for high concentrations of suspended sediments is reported in Appendix B.

Problems related to photomaps

153. Although it would appear that up to 64 shades of gray could be used to represent the various classes of suspended material concentration, the results of this study suggest that the actual number is much less. In Figure 46, only two classes were used. The contrast between classes is easily seen and permits a clear distinction to be made visually between classes. By contrast, four classes were used in Figure 42. In this case, it is possible to discriminate clearly between only two or perhaps three classes. In the legend, differentiation of gray levels for the 0-10 mg/ℓ class from the white unclassified area designation is almost impossible. Also, the area of water in the 40-50 mg/ℓ class is indistinguishable from land areas. The inability to distinguish the high concentration class from land areas is the cause of a portion of the apparent discontinuity of the C&D Canal in Figures 47 and 48, and perhaps the discontinuity in the Wicomico River near Salisbury in

Figure 41. These distinctions are clear and unequivocable in the digital data, but apparently no amount of care will project the data through the vagaries of the photographic processes without serious degradation.

154. Differentiation of suspended material concentrations in portions of water bodies only one or two pixels wide, such as portions of the Wicomico River (Figures 41 and 42) and the C&D Canal (Figures 47 and 48) is almost impossible on a photomap, especially when the contrast between the water pixel gray level and the black land area is low.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

155. On the basis of this study, the following conclusions were reached:

- a. Variations in suspended material concentrations up to 60 mg/ℓ can be detected from MSS data, provided the water depth is greater than about 2 m.
- b. Radiance in MSS bands 4, 5, and 6 tends to increase linearly with suspended material concentrations between 0 and 60 mg/ℓ.
- c. Water masses containing suspended materials of different types can be differentiated, provided the spectral characteristics of the materials are detectably different.
- d. Land-water separation can be made using band 7 digital data.
- e. A small computer with 8000 words of magnetic core and two magnetic disk memory units can be used to process ERTS-1 CCT's.
- f. Photomaps provide a means of depicting suspended material distribution, provided the number of classes of suspended material concentrations is limited to about 4.

Recommendations

156. Based on the findings of this study, it is recommended that:

- a. The validity of the technique for detecting variations in suspended material concentration be tested under conditions where concentrations are greater than 60 mg/ℓ. (This recommendation is addressed in Appendix B.)
- b. As another step toward attaining the ultimate goal of predicting the spectral composition of various suspended material concentrations, studies be initiated that will lead to an understanding of the effects of atmospheric and sea-state conditions in terms applicable to remote detection using ERTS-type multispectral scanners.
- c. The information portrayal capability of photomaps be improved by depicting classes as colors instead of gray shades. This would substantially increase the number of classes that can be distinguished.

d. Additional scenes of the five study areas with concurrent ground control data be studied to determine flushing actions and suspended material dispersion.

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Table 1

Devices Used in Manual Data Collection

Measurement	Description	Range	Accuracy
	Water Quality		
pH	Reference electrode and measuring electrode in single combination probe	2 - 12 pH	±0.1 pH
pH	Orion, Model 407 specific ion meter with Sargent-Welch combination pH electrode*	2 - 12 pH	±0.01 pH
Conductivity	Induction coil conductivity probe	0.65 mmho/cm	±0.02 mmho/cm
Temperature	Inter Ocean Systems linearized thermistor in a stainless steel shroud	-5- + 45°C	±0.02°C
Temperature	Mercury thermometer**	-5- + 45°C	±1.0°C
Dissolved oxygen	Platinum cathode and silver anode in a solution of potassium chloride	0.20 ppm	±0.2 ppm
Salinity	Computed from output of the conductivity and temperature probes	0 - 40 ppm	±0.02 ppm
	Water Current Speed		
Current velocity	General Oceanics flow meter	0 - >5 cm/sec	±10 percent of measured value
	Water Color and Turbidity		
Turbidity (optical transparency)	Secchi disc (white disc, 30 cm in diameter, attached at center to a calibrated line)	NA	NA
Water color	Forel-Ule color comparator† (16 numbered vials containing variously colored fluids)	NA	NA

* Only a few measurements were made with this instrument.

** Used only in cases where the thermistors were not available.

† Measurement is made by lowering secchi disc to a depth of 1 m (0.5 m if disc is not visible at 1 m); the apparent color of the secchi disc is then matched to one of the vials.

Table 2

Organization of Ground Control Sampling Effort

Study Area	Laboratory/Institution	Method	Data Collection Station Nos.	Remarks
York River	Norfolk District, CE	Boat	1-18	Stations 14-18 not sampled because of high waves
Wicomico River	Chesapeake Biological Laboratory, University of Maryland	Boat	1-11	
Rappahannock River	Norfolk District, CE	Boat	1-19	
Choptank	National Marine Fisheries Service	Boat	1-15	
C&D Canal	Chesapeake Bay Institute of Johns Hopkins Univ.	Boat	1-4	
	Philadephia District, CE	Piers	5-8	
	WES, CE	Boat	9-12	Boat provided by Philadelphia District, CE

Table 3

Ground Control Data Manually Collected

Station No.	Time Hours	Current Direction Degrees	Current Speed cm/sec	Suspended Material Concentration mg/ℓ	Secchi Depth m	Forel-Ule Color	Salinity ppt	Conductivity mmho/cm	Temperature °C	Dissolved Oxygen ppm	pH
				York River and Vicinity							
1	0803	180	197	19.0	0.51	XVII	3.5	--	18.3	--	--
2	0830	180	639	23.2	0.43	XVII	1.7	--	19.4	--	--
3	0845	180	446	27.7	0.36	XIX	2.3	--	20.0	--	--
4	0901	180	485	23.1	0.48	XV	2.9	--	20.5	--	--
5	0913	180	335	20.7	0.51	XIV	3.7	--	21.1	--	--
6	0935	180	140	13.9	0.71	XV	6.5	--	21.1	--	--
7	1007	0	219	21.4	0.74	XIV	9.5	--	20.5	--	--
8	1040	0	468	15.7	0.91	XII	12.2	--	21.1	--	--
9	0800	135	397	12.1	0.79	XVI	12.6	--	16.7	--	--
10	0825	315	23	12.7	1.04	XIV	16.3	--	17.8	--	--
11	0855	315	51	7.3	1.10	XVI	16.3	--	18.6	--	--
12	0915	315	396	10.5	1.55	XII	19.2	--	18.6	--	--
13	0945	315	262	23.1	1.75	XVI	19.2	--	18.6	--	--
				Wicomico River							
1	1006	slack		11.7	0.61	XXI	0.05	0.07	16.29	7.03	--
2	1038	slack		29.0	0.46	XXI	0.05	0.07	16.13	7.09	--
3	1055	slack		20.0	0.61	XXI	0.07	0.31	16.21	9.04	--
4	1107	slack		23.1	0.55	XXI	0.10	0.17	16.70	7.09	--
5	1115	slack		20.2	0.55	XXI-XIX	0.11	0.15	16.81	7.05	--
6	1122	slack		31.1	0.49	XXI-XIX	0.12	0.19	17.00	6.85	--
7	1148	slack		26.9	0.49	XIX	1.35	1.85	17.20	6.40	--
8	1156	slack		30.0	0.55	XVII	4.37	5.53	17.15	6.98	--
9	1208	slack		65.6	0.61	XVII	8.16	10.55	16.12	7.94	--
10	1220	slack		--	0.61	XVII	10.90	13.85	15.75	8.07	--
11	1234	slack		--	0.67	XVII	12.17	16.09	16.13	8.34	--
				Rappahannock River and Vicinity							
1	0730	150	21	29.5	--	--	11.4	--	16.4	--	--
2	0820	143	331	10.6	--	--	9.2	--	16.4	--	--
3	0840	170	328	17.9	--	--	10.8	--	16.4	--	--
4	0910	210	189	--	--	--	11.9	--	16.4	--	--
5	0940	150	650	6.4	--	--	12.7	--	16.4	--	--
6	1020	180	490	6.8	--	--	13.7	--	16.4	--	--
7	1005	090	153	6.5	1.50	X	13.7	--	18.9	--	--
8	0945	045	172	7.2	1.64	X	14.9	--	18.3	--	--
9	0905	215	205	9.8	1.78	X	15.3	--	18.3	--	--
10	0835	045	255	28.2	2.15	XIV	15.6	--	18.9	--	--
11	0805	215	173	11.7	2.40	X	16.3	--	16.4	--	--
12	0710	045	210	5.4	--	--	15.3	--	16.4	--	--
13	1200	215	293	8.0	1.90	X	16.3	--	19.4	--	--
14	1225	045	265	5.5	0.91	VI	17.0	--	17.8	--	--
15	1255	--	--	8.1	--	--	18.5	--	18.9	--	--
16	1315	--	--	7.3	--	--	20.1	--	18.9	--	--
17	1345	--	--	5.2	--	--	20.1	--	19.4	--	--
18	1400	045	690	5.4	2.42	XIV	21.4	--	18.9	--	--
19	1445	045	99	7.6	1.65	VIII	20.3	--	18.9	--	--
				Choptank River and Vicinity							
1	1035	225	200	11.6	0.67	VII	12.25	--	16.0	8.0	--
2	1116	300	50	20.3	0.75	VII	12.25	--	17.5	8.2	--
3	1204	200	32	10.7	0.75	VII	11.63	--	17.7	8.4	--
4	1235	200	22	10.3	1.30	XV	11.23	--	17.6	8.6	--
5	1310	210	62	9.0	1.00	XV	11.44	--	17.7	8.5	--
6	1006	115	268	29.7	1.00	XII	10.8	14.0	16.5	8.2	--
7	1038	050	248	55.2	1.50	XII	10.3	13.5	16.5	8.4	--
8	1108	095	291	56.1	1.80	XII	9.8	13.0	16.9	7.7	--
9	1134	105	140	35.3	1.30	XII	9.8	13.0	16.9	7.9	--
10	1205	145	67	23.3	1.30	XII	9.1	12.0	16.2	8.0	--
11	1205	178	178	35.5	1.60	--	13.50	18.43	16.71	7.08	--
12	1135	204	250	43.9	1.60	--	14.10	19.95	18.36	6.53	--
13	1105	225	122	53.1	1.50	--	13.78	19.54	18.68	6.15	--
14	1035	225	278	59.8	0.85	--	13.76	19.56	18.70	6.35	--
15	1005	225	203	22.0	1.10	--	13.81	18.32	17.63	7.04	--
				Elk River, C&D Canal, Delaware Bay							
1	1125	045	138	17.6	1.03	--	1.30	--	15.5	--	--
2	1145	045	205	16.9	1.40	--	2.50	--	16.1	--	--
3	1200	045	148	14.0	1.30	--	4.10	--	16.7	--	--
4	1223	225	112	8.0	1.60	--	5.50	--	16.7	--	--
5	1103	slack		15.5	0.70	XVII-XIX	5.26	7.26	15.72	--	--
6	1145	slack		17.4	0.80	XVII-XIX	5.57	8.12	16.55	--	--
7	1230	270	283	16.9	0.60	XV-XVI	6.27	9.18	16.99	--	--
8	1320	270	--	60.6	--	XVIII-XXI	6.79	10.17	18.06	--	--
9	1025	330	570	49.6	0.85	XVI	5.30	--	16.7	--	7.5
10	1105	330	810	35.7	0.65	XV	6.50	--	17.2	--	7.7
11	1135	340	740	91.5	0.50	XVI	6.90	--	17.2	--	7.3
12	1200	010	424	77.5	0.40	XVI	8.20	--	16.7	--	7.8

Note: All data were collected on 10 October 1972.

Table 4

CCT Compression Table and Equivalent Radiance Values

Decompressed Data Band Numbers 4	5	6	Compressed Data	Equivalent Radiance Value, mW/cm^2-sr Band Numbers 4	5	6
0	0	0	0	0	0	0
1	1	1	1	0.06	0.04	0.04
2	2	2	2	0.11	0.09	0.08
2	2	2	3	0.17	0.13	0.12
3	3	3	4	0.23	0.17	0.16
4	4	4	5	0.29	0.21	0.21
5	5	5	6	0.34	0.25	0.25
6	6	6	7	0.40	0.30	0.29
7	7	7	8	0.46	0.34	0.33
8	8	8	9	0.51	0.38	0.37
9	9	9	10	0.57	0.42	0.41
10	10	10	11	0.63	0.47	0.45
11	11	11	12	0.69	0.51	0.49
12	12	12	13	0.74	0.55	0.53
13	13	13	14	0.80	0.59	0.58
14	14	14	15	0.86	0.64	0.62
--	15	--	15	--	0.64	--
15	16	15	16	0.91	0.68	0.66
16	--	16	16	0.91	--	0.66
17	17	17	17	0.97	0.72	0.70
18	18	18	18	1.03	0.76	0.74
19	19	19	19	1.08	0.80	0.78
20	20	20	20	1.14	0.85	0.82
21	21	21	20	1.14	0.85	0.82
22	22	22	21	1.20	0.89	0.86
23	23	23	22	1.26	0.93	0.90
24	24	24	22	1.26	0.93	0.90
25	25	25	23	1.31	0.97	0.95
--	26	--	23	--	0.97	--
26	27	26	24	1.37	1.02	0.99
27	--	27	24	1.37	--	0.99
28	28	28	25	1.43	1.06	1.03
29	29	29	25	1.43	1.06	1.03
30	30	30	26	1.48	1.10	1.07
31	31	31	26	1.48	1.10	1.07
32	32	32	27	1.54	1.14	1.11
--	33	--	27	--	1.14	--
33	34	33	28	1.60	1.19	1.15
34	35	34	28	1.60	1.19	1.15
35	36	35	29	1.65	1.23	1.19
36	37	36	29	1.65	1.23	1.19
37	38	37	30	1.71	1.27	1.23
38	--	38	30	1.71	--	1.23
39	39	39	31	1.77	1.31	1.27
40	40	40	31	1.77	1.31	1.27
41	41	41	32	1.83	1.35	1.32

Decompressed Data Band Numbers 4	5	6	Compressed Data	Equivalent Radiance Value, mW/cm^2-sr Band Numbers 4	5	6
42	42	42	32	1.83	1.35	1.32
43	43	43	33	1.88	1.40	1.36
44	44	44	33	1.88	1.40	1.36
45	45	45	34	1.94	1.44	1.40
--	46	--	34	--	1.44	--
46	47	46	35	1.20	1.48	1.44
47	48	47	35	1.20	1.48	1.44
48	49	48	36	2.05	1.52	1.48
49	50	49	36	2.05	1.52	1.48
50	51	50	37	2.11	1.57	1.52
51	52	51	37	2.11	1.57	1.52
52	53	52	38	2.17	1.61	1.56
53	--	53	38	2.17	--	1.56
54	54	54	39	2.23	1.65	1.60
55	55	55	39	2.23	1.65	1.60
56	56	56	39	2.23	1.65	1.60
57	57	57	39	2.23	1.65	1.60
58	58	58	40	2.28	1.69	1.64
59	59	59	40	2.28	1.69	1.64
60	60	60	41	2.34	1.74	1.68
61	61	61	41	2.34	1.74	1.68
--	62	--	41	--	1.74	--
62	63	62	42	2.40	1.78	1.73
63	64	63	42	2.40	1.78	1.73
64	65	64	42	2.40	1.78	1.73
65	66	65	43	2.45	1.82	1.77
66	67	66	43	2.45	1.82	1.77
--	68	--	43	--	1.82	--
67	69	67	44	2.51	1.86	1.81
68	70	68	44	2.51	1.86	1.81
69	--	69	44	2.51	--	1.81
70	71	70	45	2.57	1.91	1.85
71	72	71	45	2.57	1.91	1.85
72	73	72	45	2.57	1.91	1.85
73	74	73	46	2.62	1.95	1.89
74	75	74	46	2.62	1.95	1.89
75	76	75	46	2.62	1.95	1.89
76	77	76	47	2.68	1.99	1.93
77	78	77	47	2.68	1.99	1.93
78	79	78	47	2.68	1.99	1.93
79	80	79	48	2.74	2.03	1.97
80	81	80	48	2.74	2.03	1.97
81	82	81	48	2.74	2.03	1.97
82	83	82	49	2.80	2.07	2.01
83	84	83	49	2.80	2.07	2.01
--	85	--	49	--	2.07	--

Decompressed Data Band Numbers 4	5	6	Compressed Data	Equivalent Radiance Value, mW/cm^2-sr Band Numbers 4	5	6
84	86	84	50	2.85	2.12	2.05
85	87	85	50	2.85	2.12	2.05
86	--	86	50	2.85	--	2.05
87	88	87	51	2.91	2.16	2.10
88	89	88	51	2.91	2.16	2.10
89	90	89	51	2.01	2.16	2.10
90	91	90	52	2.97	2.20	2.14
91	92	91	52	2.97	2.20	2.14
92	93	92	52	2.87	2.20	2.14
93	94	93	53	3.02	2.24	2.18
95	96	95	53	3.02	2.24	2.18
96	97	96	54	3.08	2.29	2.22
97	98	97	54	3.08	2.29	2.22
98	99	98	54	3.08	2.29	2.22
99	100	99	55	3.14	2.33	2.26
100	101	100	55	3.14	2.33	2.26
101	102	101	55	3.14	2.33	2.26
--	103	--	55	--	2.33	--
102	104	102	56	3.20	2.37	2.30
103	105	103	56	3.20	2.37	2.30
104	106	104	56	3.20	2.37	2.30
105	--	105	56	3.20	--	2.30
106	107	106	57	3.25	2.41	2.34
107	108	107	57	3.25	2.41	2.34
108	--	108	57	3.25	--	2.34
109	109	109	58	3.31	2.46	2.38
110	110	110	58	3.31	2.46	2.38
111	111	111	58	3.31	2.46	2.38
112	112	112	59	3.37	2.50	2.42
113	113	113	59	3.37	2.50	2.42
114	114	114	59	3.37	2.50	2.42
115	115	115	60	3.42	2.54	2.47
116	116	116	60	3.42	2.54	2.47
117	--	117	60	3.42	--	2.47
118	117	118	61	3.48	2.58	2.51
119	118	119	61	3.48	2.58	2.51
120	119	120	61	3.48	2.58	2.51
121	120	121	62	3.54	2.62	2.55
122	121	122	62	3.54	2.62	2.55
123	--	123	62	3.54	--	2.55
124	122	124	63	3.59	2.67	2.59
--	123	--	63	--	2.67	--
125	124	125	63	3.59	2.67	2.59
126	125	126	63	3.59	2.67	2.59
--	126	--	63	--	2.67	--
--	127	--	63	--	2.67	--

Table 5

Correlations of Radiance Values With Suspended Material Concentration

Station No.	Suspended Material Concentration mg/ℓ	Radiance, mW/cm^2-sr MSS Band* 4	5	6
	York River and Vicinity			
1	19.0	1.27	0.63	0.30
2	23.2	1.51	0.79	0.45
3	27.7	1.39	0.75	0.34
4	23.1	1.33	0.72	0.30
5	20.7	1.27	0.59	0.28
6	13.9	1.22	0.48	0.20
7	21.4	1.25	0.61	0.30
8	15.7	1.27	0.56	0.26
9	12.1	1.39	0.65	0.34
10	12.7	1.19	0.48	0.22
11	7.3	1.13	0.48	0.20
12	10.5	1.16	0.44	0.22
13	23.1	1.14	0.42	0.18
	Wicomico River			
1	11.7	1.14	0.55	0.28
2	29.0	1.16	0.61	0.43
3	20.0	1.11	0.44	0.28
4	23.1	1.08	0.46	0.36
5	20.2	1.05	0.46	0.32
6	31.1	1.08	0.50	0.34
7	26.9	1.16	0.57	0.34
8	30.0	1.16	0.57	0.34
9	65.6	1.16	0.57	0.34
10	--		Data not available	
11	--		Data not available	
	Rappahannock River and Vicinity			
1	29.5	1.48	0.65	0.26
2	10.6	1.39	0.65	0.26

(Continued)

* Radiance values in this table are the arithmetic mean of the high and low radiance value in a 3- by 3-array in which the central point is the point corresponding to the data collection station.

(Sheet 1 of 3)

Table 5 (Continued)

Station No.	Suspended Material Concentration mg/ℓ	Radiance, mW/cm^2-sr MSS Band 4	5	6
	Rappahannock River and Vicinity (Continued)			
3	17.9	1.37	0.55	0.24
4	--	--	--	--
5	6.4	1.17	0.44	0.16
6	6.8	1.19	0.46	0.20
7	6.5	1.11	0.40	0.18
8	7.2	1.11	0.44	0.16
9	9.8	1.06	0.40	0.16
10	28.2	1.08	0.40	0.14
11	11.7	1.14	0.42	0.22
12	5.4	1.11	0.36	0.20
13	8.0	1.19	0.44	0.22
14	5.5	1.17	0.44	0.22
15	8.1	1.20	0.40	0.18
16	7.3	1.08	0.48	0.18
17	5.2	1.11	0.38	0.18
18	5.4	1.11	0.40	0.16
19	7.6	1.28	0.40	0.20
	Choptank River and Vicinity			
1	11.6	1.33	0.59	0.24
2	20.3	1.19	0.48	0.20
3	10.7	1.13	0.48	0.18
4	10.3	1.16	0.44	0.22
5	9.0	1.16	0.46	0.20
6	29.7	1.16	0.44	0.18
7	55.2	1.13	0.44	0.20
8	56.1	1.16	0.46	0.20
9	35.3	1.13	0.44	0.18
10	23.3	1.10	0.44	0.18
11	35.5	1.13	0.44	0.18
12	43.9	1.16	0.44	0.18
13	53.1	1.08	0.42	0.16
14	59.8	1.16	0.48	0.16
15	22.0	Data not available		
	Elk River, C&D Canal, Delaware Bay			
1	17.6	1.14	0.55	0.32
2	16.9	1.08	0.55	0.24

(Continued)

Table 5 (Concluded)

Station No.	Suspended Material Concentration mg/ℓ	Radiance, mW/cm^2-sr MSS Band 4	5	6
	Elk River, C&D Canal, Delaware Bay (Continued)			
3	14.0	1.14	0.55	0.28
4	8.0	1.08	0.55	0.24
5	15.5	1.14	0.59	0.32
6	17.4	1.14	0.63	0.41
7	16.9	1.14	0.76	0.36
8	160.6	1.25	0.63	0.36
9	49.6	1.19	0.63	0.32
10	35.7	1.14	0.63	0.36
11	91.5	1.14	0.63	0.36
12	77.5	1.14	0.67	0.45

Table 6

Evaluations of Reliability of Radiance Values

At Data Collection Stations

Study Area and Station No.	Accepted	Rejected	Reason for Rejection
York River			
1	x		
2		x	Possibly reflection from bank or a different kind of suspended material
3	x		
4	x		
5	x		
6	x		
7	x		
8	x		
9		x	Water perhaps too shallow
10	x		
11	x		
12	x		
13		x	Influenced by bay water, probably, with different kind of suspended material
14 15 16 17 18			Suspended material concentration samples not taken
Wicomico River			
1		x	Probably influenced by industrial waste; different type of suspended material
2	x		
3	x		
4	x		
5	x		
6		x	Shadows cast by shoreline features
Wicomico River (Continued)			
7	x		
8		x	Probably influenced by bay water with different suspended material
9		x	Probably influenced by bay water with different suspended material
10			Suspended material concentration sample not taken
11			Suspended material concentration sample not taken
Rappahannock River			
1	x		
2		x	Wave action
3	x		
4			Suspended material concentration sample not taken
5	x		
6	x		
7	x		
8	x		
9		x	Probably influenced by bay water with different suspended material
10		x	Probably influenced by bay water with different suspended material
11		x	Probably influenced by bay water with different suspended material
12		x	Probably influenced by bay water with different suspended material
13		x	Probably influenced by bay water with different suspended material

(Continued)

Table 6 (Concluded)

Study Area and Station No.	Accepted	Rejected	Reason for Rejection
Rappahannock River (Continued)			
14		x	Probably influenced by bay water with different suspended material
15		x	Probably influenced by bay water with different suspended material
16		x	Probably influenced by bay water with different suspended material
17		x	Probably influenced by bay water with different suspended material
18		x	Probably influenced by bay water with different suspended material
19		x	Probably influenced by bay water with different suspended material
Choptank River			
1	x		
2		x	Different material type or wave action
3		x	Different material type or wave action
4	x		
5	x		
6		x	Different type of material
7		x	Different type of material
8		x	Different type of material
9		x	Different type of material
10		x	Different type of material
11		x	Probably influenced by bay water with different suspended material
12		x	Probably influenced by bay water with different suspended material
13		x	Probably influenced by bay water with different suspended material
Choptank River (Continued)			
14		x	Probably influenced by bay water with different suspended material
15			Radiance values not available
Chesapeake and Delaware Canal			
1		x	Possibly shallow water
2		x	Possibly shallow water
3		x	Possibly shallow water
4	x		
5	x		
6	x		
7		x	Different type of material
8		x	Different type of material
9		x	Different type of material
10		x	Different type of material
11		x	Different type of material
12		x	Different type of material

Table 7

Suspended Material Concentration Classes

Class	Suspended Material Concentration Ranges mg/ℓ	Radiance, mW/cm²-sr MSS Bands 4	5	6
		York River and Vicinity		
1	0-15	1.08-1.20 (19-21)	0.42-0.51 (10-12)	0.21-0.33 (5-8)
2	15-25	1.14-1.26 (20-22)	0.55-0.68 (13-16)	0.25-0.37 (6-9)
3	>25	1.20-1.31 (21-23)	0.72-0.80 (17-19)	0.33-0.41 (8-10)
		Wicomico River (No. 1)		
1	0-25	0.80-1.14 (14-20)	0.04-0.55 (1-13)	0.04-0.37 (1-9)
2	25-50	1.08-1.43 (19-25)	0.51-1.06 (12-25)	0.33-0.70 (8-17)
		Wicomico River (No. 2)		
1	0-10	0.80-1.03 (14-18)	0.04-0.30 (1-7)	0.04-0.21 (1-5)
2	10-25	0.97-1.14 (17-20)	0.21-0.55 (5-13)	0.33-0.58 (4-9)
3	25-40	1.08-1.31 (19-23)	0.51-0.85 (12-20)	0.33-0.58 (8-14)
4	40-50	1.26-1.43 (22-25)	0.76-1.06 (18-25)	0.49-0.70 (12-17)
		Rappahannock River and Vicinity		
1	0-15	1.03-1.26 (18-22)	0.38-0.55 (9-13)	0.12-0.25 (3-6)
2	15-25	1.14-1.31 (20-23)	0.51-0.68 (12-16)	0.21-0.29 (5-7)
3	25-30	1.26-1.37 (22-24)	0.59-0.72 (14-17)	0.25-0.33 (6-8)

(Continued)

Note: Numbers in parenthesis are CCT values corresponding to radiance values shown.

Table 7 (Concluded)

Class	Suspended Material Concentration Ranges mg/ℓ	Radiance, mW/cm^2-sr MSS Bands 4	5	6
	Choptank River and Vicinity (Population No. 1)			
1	0-12	0.80-1.31 (14-23)	0.25-0.55 (6-13)	0.04-0.25 (1-6)
2	12-15	1.20-1.43 (21-25)	0.51-0.72 (12-17)	0.21-0.37 (5-9)
	Choptank River and Vicinity (Population No. 2)			
1	0-25	1.03-1.14 (18-20)	0.38-0.47 (9-11)	0.12-0.21 (3-5)
2	25-60	1.08-1.26 (19-22)	0.42-0.51 (10-12)	0.16-0.25 (4-6)
	Chesapeake and Delaware Canal and Vicinity			
1	0-12	0.97-1.14 (17-20)	0.47-0.59 (11-14)	0.08-0.33 (2-8)
2	12-25	1.08-1.26 (19-22)	0.55-0.72 (13-17)	0.29-0.53 (7-13)
3	25-42	1.20-1.37 (21-24)	0.68-0.85 (16-20)	0.49-0.82 (12-20)

Table 8

Film Writer Calibration Data

Step No.	Computer Tape Value*	Desired Optical Density	Measured Optical Density
1	000	0.00	0.07
2	013	0.15	0.09
3	026	0.30	0.17
4	038	0.45	0.33
5	051	0.60	0.51
6	064	0.75	0.64
7	077	0.90	0.78
8	089	1.05	0.91
9	102	1.20	1.04
10	115	1.35	1.15
11	128	1.50	1.28
12	140	1.65	1.42
13	153	1.80	1.59
14	166	1.95	1.79
15	179	2.10	1.95
16	191	2.25	2.07
17	204	2.40	2.17
18	217	2.55	2.24
19	230	2.70	2.30
20	242	2.85	2.35
21	255	3.00	2.42

* Or light intensity value.

APPENDIX A: EXPERIENCE WITH AUTOMATED DATA COLLECTION SYSTEMS

1. Attempts were made during the study described in the main body of this report to use two different kinds of automated data acquisition systems. The incentive to use such systems stems from the very considerable cost of acquiring ground control data by conventional means, and from the fact that it is physically impossible to obtain ground control information (water samples and related data) from a large number of data collection stations at the instant of the satellite overpass without an inordinate outlay of manpower and equipment. If automated data acquisition systems can be effectively used, it seems certain that their careful design will result in substantially reduced data collection costs. Further, the data collection systems could be activated at appropriate times, thus ensuring that data are available for all stations during the very short interval that the satellite is overhead.

System Characteristics

2. Two systems were deployed--the NASA-provided Data Collection Platform (DCP) and WES-designed automated data collection system. One of each system type was emplaced on a pier at station 7A on the Rappahannock River (Figure 9 of the main text) and station 10A on the Choptank River (Figure 10 of the main text).

Data collection platforms

3. The DCP's were obtained and readied for operation with the assistance and cooperation of personnel from NASA Langley Research Center. Water quality monitoring systems (Figure A1), supplied by WES, were interconnected to the DCP's, as shown schematically in Figure A2. The instruments were emplaced on 9 October 1972. Sensors comprising the water quality monitoring system are described below.

4. Temperature sensor. The temperature probe is a factory calibrated and specially aged, glass-bead thermistor encapsulated at the closed end of a stainless steel tube. The range is 0-40°C, and accuracy is ±0.5°C.

5. <u>Conductivity sensor.</u> Conductivity was measured with a flow-through, electrode-type conductivity cell designed for in situ operations at various depths under rigorous field conditions. The cell contains pure nickel electrodes that have been gold-plated and coated with a deposit of platinum black. Electrodes are permanently mounted in the cell chambers to prevent changes in cell characteristics due to shock or impact. The range is 0-100 millimho/cm; accuracy is ±2.0 millimho/cm.

6. <u>pH sensor.</u> The pH sensor develops a potential difference between a special glass electrode and a silver-silver chloride reference electrode combination that is proportional to pH. The pH electrode is sealed to withstand an external pressure of 150 psi. Temperature compensation is incorporated to correct for sensor output levels that are due to effects of temperature changes. The range is 0-12; accuracy is ±0.01.

7. <u>Dissolved oxygen sensor.</u> The dissolved oxygen transducer consists of separate modular sensors for measuring dissolved oxygen and temperature, and a stirring mechanism. The dissolved oxygen sensor consists of a silver anode and a gold cathode enclosed in a PVC housing. A solution of potassium chloride (KCl) is used as the electrolyte. A teflon membrane, permeable to oxygen, is placed over the cathode. Oxygen diffuses through the membrane to the cathode where the chemical reaction takes place: $O_2 + 2H_2O + 4e \longrightarrow 4OH$. The related reaction at the silver anode in the electrolytic chamber is $4Ag + 4Cl- \longrightarrow 4AgCl + 4e$. A voltage potential applied across the two electrodes results in a current flow that is proportional to the partial pressure of oxygen at the probe tip. The sensor produces an output signal as long as the electrolyte is exposed to oxygen. A temperature probe (a precision thermistor) is used with the dissolved oxygen transducer to provide automatic compensation for (1) the effects of temperature on permeability of the oxygen probe membrane; and (2) variation in oxygen solubility of natural waters due to temperature change. The range is 0-20 ppm over a temperature range of 0 to 40°C; accuracy is ±0.2 ppm.

8. <u>Depth sensor.</u> The depth sensor is a standard Bourdon tube and potentiometric transducer. The Bourdon tube consists of a hollow, coil

spring mechanism that responds to pressure changes in the fluid environment to which it is exposed by expanding or contracting an amount depending on the pressure change. These responses are mechanically coupled to a potentiometer that produces a voltage output proportional to depth (pressure). The range is 0-30 m; accuracy is ± 0.6 m.

9. Data acquisition procedures. Data acquisition with the DCP is accomplished automatically. After the sensors have been connected to the DCP and the DCP is placed in operation, data are acquired when ERTS-1 is in mutual view of the transmitting DCP and one or more of the ground receiving stations. Orbit parameters allow for up to 9 min of mutual visibility, and during this time, the probability of receiving at least one valid message for a DCP every 12 hr is at least 0.95.[2] Data from the DCP's were received at a ground receiving station, processed (read, edited, reformatted, and sorted), and transmitted to WES on punched cards.

WES automatic data collection system

10. The WES automatic data collection systems (Figure A3) were interfaced to sensors as shown in Figure A4. One system was emplaced at the Rappahannock River station on 5 October 1972 and the other system was emplaced at the Choptank River site on 9 October 1972.

11. The field station and sensors comprising the WES system are described below.

12. Leach Corporation Model 101R Field Station. The field station is designed to accept the electrical signals from up to 32 sensors, convert the signals to digital form, and record the results on 1/4-in. magnetic tape. For unattended operation, an internal clock controls the operation of the field station. The clock can be manually set so that the field station will interrogate each sensor at 5-, 10-, 15-, 30-, 60-, 120-, or 240-min intervals.

13. Solar radiation sensors. Incident and reflected solar radiation were measured with Yellott Sol-A-Meters (Mark I-G Weatherproof Silicon Cell Pyranometers) manufactured by the DTI Division of Talley Industries, Inc. This device has a spectral response from 0.35 to 1.15 μm and a peak sensitivity at 0.85 μm. The instrument is designed

to produce an output of 0- to 10-mv for solar radiation from 0- to 2-cal/cm^2/min. (or 0- to 139.46 mW/cm^2). Measurement accuracies are typically $\pm$3-5 percent. Eight solar radiation sensors were used. Six of them were fitted with filters to limit the wavelengths to which they would respond. Two solar radiation sensors were fitted with each of the following filters:

Filter	Wavelength Band, μm
Wratten No. 87C	0.8-1.15 (See note)
Wratten No. 47	0.4-0.5
Wratten No. 29	0.6-1.15 (See note)

Note: The upper limit is established by the upper limit of sensitivity of the solar radiation sensor.

One of each corresponding pair of solar radiation sensors was mounted on an arm extending over the water from a pier so that it would sense incident solar radiation, and the remaining sensors were mounted on a similar arm attached to the pier so that they would respond to radiation reflected from the water. Care was taken when establishing the position for mounting the solar radiation sensors to ensure that none of the sensors would be in their own shadow or the shadow of the pier at the time ERTS-1 was overhead.

14. Wind speed sensors. Wind speed was measured with a Climet Instruments Co., Model 011-2B Wind Speed Transmitter. This device is a 0- to 2.682 km/min anemometer with a threshold of 0.03 km/min and an accuracy of $\pm$2.0 percent over its calibrated range. This model is designed for operation in environments containing natural contaminants, such as salt spray. The transmitter consists of a three-cup wind sensor that actuates a sealed magnetic reed switch by means of a magnet attached to the sensor shaft. Output signals are produced by a series of contact closures at a frequency proportional to wind speed.

15. Wind direction sensor. Wind direction was measured with a Climet Instruments Co., Model 012-2C Wind Direction Transmitter. This

instrument is designed to measure wind direction over the range 0-360° continuous with an accuracy of ±5°. Wind speed threshold for operation is 0.3 km/min. The instrument consists of an airfoil vane coupled to a microtorque potentiometer and produces a continuous d-c output signal proportional to wind direction.

16. Rainfall sensors. A Weather Measure Corp., Model P501-1 Remote Recording Rain Gage was used to measure rainfall. This instrument is a version of the tipping-bucket-type rain gage in which two chrome-plated brass buckets alternately fill and tip to cause a momentary closure of a mercury switch. Switch closures occur at a frequency proportional to rainfall. Manufacturers specifications for this instrument are as follows:

Orifice: 20 cm
Calibration: 0.025 cm
Switch: mercury, 0.1-sec closure
Accuracy: 0.5 percent (calibrated at 1.27 cm/hr)
Size: 50.8 cm high × 24.1 cm diameter

Data Reduction Procedures

17. The data reduction procedures are illustrated schematically in Figure A5. Data reduction was accomplished in four steps: data translation, error check, data conversion, and data storage.

Data translation

18. Data Collection Platform (DCP). The computer cards resulting from DCP measurements are interrogated, and those portions containing the DCP identification numbers, dates and times, and sensor measurements are reformatted to conform to the input requirements of the basic data reduction program.

19. WES automated data recording system. The output of the automated data recording system is a 1/4-in-wide magnetic tape on which data are recorded in digital form on two parallel tracks. Data in this form must be re-recorded on 1/2-in-wide magnetic tape to achieve compatibility with available automatic data processing equipment. In this process the data are recorded on six tracks and a parity track. A complete

record consists of 13 eight-frame words. The first word contains a site identification number, the second word is the starting time of the field station operation, and the remaining words are values for each of the 11 sensors used with the field station.

Error check

20. In this step, each record is checked for conformity with the format requirements for the next step--data conversion. Word length, record length, platform or site identification number, and data values are each checked. If an irregularity is detected, the entire record is flagged, but the computer program is allowed to continue running uninterruptedly.

Data conversion

21. The automated data recording system and the DCP accept electrical voltages that are analogs of the parameter being measured by each sensor. The purpose of the data conversion step is to convert these voltage analogs to more useful terms. The voltages are converted to digital form and the results are the input to the data reduction program.

22. Each sensor is calibrated prior to use to establish the relation between its output voltages and the stimuli producing them. The calibration curves that result are placed in computer storage for use in converting the voltages recorded in digital form on the magnetic tape produced by the field station or the computer cards resulting from DCP operation. The recorded data are sorted by sensor and then matched with the appropriate calibration curve to convert the sensor output to engineering terms; e.g. thermistor output converted from volts to degrees centigrade, etc.

Data storage

23. Once the data have been converted from digital form to engineering terms, they are stored on 1/2-in. magnetic tape.

Results

Data collection platforms

24. Data from the sensors connected to the two DCP's are shown in

Table A1. Although the accuracy of these data could not be field checked at the time the data were taken, conclusions concerning the reliability of the data can be drawn by comparison with data taken manually at the various data collection sites and by examination of the tabular lists.

25. Rappahannock River. Data were taken at station 7A in the Rappahannock River with DCP No. 6022. Examination of the table of measurements made at this site shows unusual discontinuities in temperature and depth measurements. Between 1658 hr on 10 October and 0102 hr on 11 October, the recorded depth showed a jump from 12.47 m to 30.00 m and remained constant at 30.0 m for the next 12 hr. Since the depth probe was installed at a fixed depth and not moved therefrom, this jump suggests the possibility of instrumentation malfunction. A sharp increase in the depths measured after 1517 hr on 10 October also suggests instrumentation problems. The lack of change in the dissolved oxygen measurements over the period shown suggests that this sensor was inoperative.

26. Choptank River. Data were taken at station 11 in the Choptank River with DCP No. 6305. Examination of the data in Table A1 shows that no valid measurements were taken prior to 1507 hr on 10 October although the DCP was interrogated. After this time the lack of change in and the value of the measurements (with the possible exception of dissolved oxygen) lead to questions on the accuracy of these measurements.

Automated data recording system

27. The automated data recording system was used to measure and record wind speed, rainfall, wind direction, and solar radiation. The results are shown in Table A2.

28. Unfortunately, the solar radiation measurements failed to produce reliable results. As the sun approaches the zenith, solar radiation measurements should increase to a maximum, and then begin to decrease to a minimum as the day progresses. Except for a few instances of anamolies in the data, such as the measurement at 0200 hr or the measurement at 1415 hr at the Rappahannock River station, the solar radiation values remain constant throughout the entire record. Only

the measurements made at the Choptank River station between 1115 hr and 1545 hr with the unfiltered upward-looking solar radiation sensor indicate a change that may be related to solar angle or time of day.

Table A1

Ground Control Data Automatically Collected With

NASA Data Collection Platforms

Date			Time			Temperature °C	Depth m	Conductivity mmhos/cm	Dissolved Oxygen ppm	pH
Day	Mo	Yr	Hr	Min	Sec					
						Date Collection Platform No. 6022 Rappahannock River				
10	10	72	0	56	14	18	1.65	3	0.08	10.02
10	10	72	0	59	38	18	1.65	3	0.08	10.02
10	10	72	1	1	20	18	1.65	3	0.08	10.02
10	10	72	1	3	2	18	1.65	3	0.08	10.02
10	10	72	1	4	44	18	1.65	3	0.08	10.02
10	10	72	2	36	58	18	1.65	3	0.08	9.88
10	10	72	2	38	40	18	1.65	3	0.08	9.88
10	10	72	2	40	23	18	1.65	3	0.08	9.88
10	10	72	2	42	6	18	1.65	3	0.08	9.88
10	10	72	2	43	49	18	1.65	3	0.08	9.88
10	10	72	2	45	32	18	1.65	3	0.08	9.88
10	10	72	2	47	15	18	1.65	3	0.08	9.88
10	10	72	4	20	7	17	1.76	3	0.08	9.65
10	10	72	4	21	50	17	1.76	3	0.08	9.65
10	10	72	4	23	34	17	1.76	3	0.08	9.65
10	10	72	4	25	17	17	1.76	3	0.08	9.65
10	10	72	4	27	0	17	1.76	3	0.08	9.65
10	10	72	15	7	36	13	0.00	2	0.08	7.15
10	10	72	15	9	19	13	0.12	2	0.08	7.15
10	10	72	15	11	1	13	0.12	2	0.08	7.15
10	10	72	15	12	44	13	0.12	2	0.08	7.15
10	10	72	15	14	27	13	0.24	2	0.08	7.15
10	10	72	15	16	9	13	0.24	2	0.08	7.15
10	10	72	15	17	52	13	0.35	2	0.08	7.15
10	10	72	16	50	9	13	11.53	2	0.08	6.82
10	10	72	16	51	52	13	11.76	2	0.08	6.82
10	10	72	16	53	34	13	11.88	2	0.08	6.87
10	10	72	16	55	16	12	12.12	2	0.08	6.73
10	10	72	16	56	58	12	12.24	2	0.08	6.73
10	10	72	16	58	41	13	12.47	2	0.08	6.73
11	10	72	1	2	19	9	30.00	2	0.08	4.75
11	10	72	1	4	3	9	30.00	2	0.08	4.75
11	10	72	1	5	46	9	30.00	2	0.08	4.75
11	10	72	1	7	29	9	30.00	2	0.08	4.75
11	10	72	1	9	13	9	30.00	2	0.08	4.75

(Continued)

(Sheet 1 of 3)

Table A1 (Continued)

Date			Time			Tempera- ture °C	Depth m	Conductivity mmhos/cm	Dissolved Oxygen ppm	pH
Day	Mo	Yr	Hr	Min	Sec					
						Date Collection Platform No. 6022 Rappahannock River (Continued)				
11	10	72	1	10	56	9	30.00	2	0.08	4.75
11	10	72	2	42	36	9	30.00	2	0.08	4.52
11	10	72	2	44	20	9	30.00	2	0.08	4.52
11	10	72	2	46	4	9	30.00	2	0.08	4.52
11	10	72	2	47	48	8	30.00	2	0.08	4.52
11	10	72	2	49	33	8	30.00	2	0.08	4.47
11	10	72	2	51	17	8	30.00	2	0.08	4.47
11	10	72	2	53	1	8	30.00	2	0.08	4.52
11	10	72	4	26	59	8	30.00	2	0.08	4.38
11	10	72	4	30	28	8	30.00	2	0.08	4.38
11	10	72	4	32	12	8	30.00	2	0.08	4.38
11	10	72	13	32	45	8	30.00	2	0.08	4.19
						Data Collection Platform No. 6305 Choptank River				
10	10	72	0	54	53	0	0.00	0	0.00	0.00
10	10	72	0	56	29	0	0.00	0	0.00	0.00
10	10	72	0	58	4	0	0.00	0	0.00	0.00
10	10	72	0	59	40	0	0.00	0	0.00	0.00
10	10	72	1	1	15	0	0.00	0	0.00	0.00
10	10	72	1	2	51	0	0.00	0	0.00	0.00
10	10	72	1	4	26	0	0.00	0	0.00	0.00
10	10	72	1	6	2	0	0.00	0	0.00	0.00
10	10	72	2	37	0	0	0.00	0	0.00	0.00
10	10	72	2	38	36	0	0.00	0	0.00	0.00
10	10	72	2	40	12	0	0.00	0	0.00	0.00
10	10	72	2	41	48	0	0.00	0	0.00	0.00
10	10	72	2	43	24	0	0.00	0	0.00	0.00
10	10	72	2	45	0	0	0.00	0	0.00	0.00
10	10	72	2	46	36	0	0.00	0	0.00	0.00
10	10	72	2	48	12	0	0.00	0	0.00	0.00
10	10	72	4	21	24	0	0.00	0	0.00	0.00
10	10	72	4	23	1	0	0.00	0	0.00	0.00
10	10	72	4	24	38	0	0.00	0	0.00	0.00
10	10	72	4	26	14	0	0.00	0	0.00	0.00
10	10	72	4	27	51	0	0.00	0	0.00	0.00
10	10	72	15	7	6	40	1.29	3	7.53	12.00

(Continued)

Table A1 (Concluded)

Date			Time			Temperature °C	Depth m	Conductivity mmhos/cm	Dissolved Oxygen ppm	pH
Day	Mo	Yr	Hr	Min	Sec					
Data Collection Platform No. 6305 Choptank River (Continued)										
10	10	72	15	8	42	40	1.29	3	7.57	12.00
10	10	72	15	10	19	40	1.29	3	7.53	12.00
10	10	72	15	11	56	40	1.29	3	7.57	12.00
10	10	72	15	13	33	40	1.29	3	7.61	12.00
10	10	72	15	15	10	40	1.29	3	7.61	12.00
10	10	72	15	16	47	40	1.29	3	7.61	12.00
10	10	72	16	49	56	40	1.29	3	7.80	12.00
10	10	72	16	51	32	40	1.29	3	7.76	12.00
10	10	72	16	53	8	40	1.29	3	7.80	12.00
10	10	72	16	54	44	40	1.29	3	7.80	12.00
10	10	72	16	56	20	40	1.29	3	7.80	12.00
10	10	72	16	57	55	40	1.29	3	7.80	12.00
10	10	72	17	1	7	40	1.29	3	7.80	12.00
11	10	72	1	2	5	40	1.65	3	7.88	12.00
11	10	72	1	3	42	40	1.65	3	7.84	12.00
11	10	72	1	5	20	40	1.65	3	7.84	12.00
11	10	72	1	6	57	40	1.65	3	7.84	12.00
11	10	72	1	8	34	40	1.65	3	7.84	12.00
11	10	72	1	10	12	40	1.65	3	7.84	12.00
11	10	72	1	11	49	40	1.65	3	7.84	12.00
11	10	72	2	41	38	40	1.29	3	7.65	11.62
11	10	72	2	43	17	40	1.29	3	7.65	11.62
11	10	72	2	44	55	40	1.29	3	7.61	11.62
11	10	72	2	46	33	40	1.29	3	7.61	11.62
11	10	72	2	48	12	40	1.29	3	7.65	11.62

Table A2

Ground Control Data Collected With WES Automated Data Collection System

					Solar Radiation Cal/cm^2/min							
Identification	Time hr/min	Wind Speed mph 0	Rain in. 1	Wind Direction Degrees 2	Filter 87C-UP 3	Filter 87C-DN 4	Filter 47-UP 5	Filter 47-DN 6	No Filter UP 7	No Filter DN* 8	Filter 29-UP* 9	Filter 29-DN 10
NEW DAY 10 OCT 72				ERTS-1 Chesapeake Bay Study Rappahannock River								
1	0.15	9.43	0.00	4.50	0.01	0.09	0.13	0.00	0.34	0.05	0.21	0.08
1	0.30	9.52	0.00	0.00	0.01	0.09	0.13	0.00	0.34	0.05	0.23	0.08
1	0.45	9.44	0.00	354.00	0.08	0.09	0.13	0.00	0.34	0.05	0.23	0.08
1	1.00	9.42	0.00	342.00	0.01	0.09	0.04	0.00	0.34	0.05	0.23	0.08
1	1.15	9.42	0.00	359.50	0.01	0.09	0.13	0.00	0.34	0.05	0.23	0.08
1	1.30	9.41	0.00	337.50	0.01	0.09	0.13	0.00	0.34	0.05	0.23	0.08
1	1.45	9.42	0.00	355.50	0.01	0.09	0.13	0.00	0.34	0.05	0.05	0.08
1	2.00	9.00	3.65	216.50	0.04	0.28	0.06	0.65	0.11	0.42	0.07	0.47
1	2.15	9.30	0.00	340.50	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	2.30	9.30	0.00	329.00	0.01	0.09	0.13	0.00	0.34	0.05	0.23	0.08
1	2.45	9.27	0.00	355.50	0.01	0.09	0.13	0.00	0.09	0.05	0.23	0.08
1	3.00	9.30	0.00	32.50	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	3.15	9.47	0.00	18.50	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	3.30	9.48	0.00	351.50	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	3.45	9.42	0.00	18.00	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	4.00	9.35	0.00	37.00	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	4.15	9.21	0.00	7.00	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	4.30	9.22	0.00	31.50	0.01	0.09	0.13	0.00	0.32	0.05	0.23	0.08
1	4.45	9.26	0.00	357.50	0.01	0.09	0.13	0.00	0.32	0.05	0.05	0.08
1	5.00	10.23	0.00	337.00	0.01	0.09	0.11	0.00	0.29	0.05	0.19	0.08
1	5.15	10.69	0.00	319.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	5.30	9.43	0.00	332.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	5.45	9.44	0.00	319.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	6.00	9.46	0.00	344.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	6.15	9.47	0.00	341.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	6.30	9.34	0.00	323.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	6.45	9.43	0.00	332.50	0.01	0.09	0.04	0.00	0.23	0.05	0.05	0.08
1	7.00	9.43	0.00	354.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	7.15	9.48	0.00	353.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	7.30	9.45	0.00	351.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	7.45	9.25	0.00	324.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	8.00	9.15	0.00	347.50	0.01	0.09	0.04	0.00	0.09	0.05	0.05	0.08
1	8.15	9.00	6.50	108.50	0.01	0.09	0.04	0.18	0.09	0.14	0.05	0.47
1	8.30	9.56	0.00	320.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	8.45	9.50	0.00	328.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	9.00	9.29	0.00	322.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	9.15	9.29	0.00	336.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	9.30	9.14	0.00	352.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	9.45	9.00	0.00	355.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	10.00	9.24	0.00	352.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	10.15	9.23	0.00	342.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	10.30	9.28	0.00	351.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	10.45	9.32	0.00	339.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	11.00	9.23	0.00	334.50	0.01	0.09	0.04	0.00	0.23	0.05	0.07	0.08
1	11.15	9.22	4.48	106.00	1.33	1.18	1.19	3.78	1.09	12.48	1.18	16.00
1	11.30	9.31	0.00	316.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	11.45	9.37	0.00	336.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	12.00	9.36	0.00	326.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	12.15	9.42	0.00	320.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	12.30	9.31	0.00	318.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	12.45	9.45	0.00	328.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	13.00	9.46	0.00	324.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	13.15	9.49	0.00	326.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	13.30	9.50	0.00	337.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	13.45	9.45	0.00	331.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	14.00	9.45	0.00	336.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	14.15	10.23	2.13	179.00	1.33	1.18	3.48	1.26	11.06	1.18	17.00	0.47
1	14.30	9.30	0.00	332.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	14.45	9.35	0.00	319.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	15.00	9.30	0.00	316.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	15.15	9.21	0.00	302.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	15.30	9.17	0.00	304.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	15.45	9.12	0.00	305.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	16.00	9.17	0.00	287.50	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	16.15	9.17	0.00	301.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	16.30	9.20	0.00	307.00	0.01	0.09	0.04	0.00	0.23	0.05	0.14	0.08
1	16.45	9.16	0.00	308.50	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	17.00	9.37	0.00	350.00	0.01	0.09	0.04	0.00	0.23	0.05	0.05	0.08
1	17.15	9.01	1.00	358.50	0.10	0.16	0.11	1.34	0.18	0.83	0.12	0.08
1	17.30	9.40	0.00	308.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	17.45	9.24	0.00	327.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	18.00	9.25	0.00	299.50	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	18.15	9.36	0.00	326.50	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	18.30	9.36	0.00	334.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08

(Continued)

* Sensors uncalibrated.

Table A2 (Continued)

Identification	Time hr/min	Wind Speed mph 0	Rain in. 1	Wind Direction Degrees 2	Solar Radiation Cal/cm²/min Filter 87C-UP 3	Filter 87C-DN 4	Filter 47-UP 5	Filter 47-DN 6	No Filter UP 7	No Filter DN* 8	Filter 29-UP* 9	Filter 29-DN 10
NEW DAY 10 OCT 72 (Continued)					ERTS-1 Chesapeake Bay Study Rappahannock River (Continued)							
1	18.45	9.37	0.00	334.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	19.00	9.37	0.00	322.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	19.15	9.23	0.00	0.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	19.30	9.24	0.00	354.50	0.01	0.09	0.04	0.00	0.09	0.05	0.14	0.08
1	19.45	9.23	0.00	339.00	0.01	0.09	0.04	0.00	0.21	0.05	0.14	0.08
1	20.00	9.16	0.00	19.50	0.01	0.09	0.04	0.00	0.21	0.05	0.05	0.08
1	20.15	10.00	0.00	323.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	20.30	9.31	0.00	309.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	20.45	9.25	0.00	337.00	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	21.00	9.34	0.00	333.00	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	21.45	9.25	0.00	338.00	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	21.30	9.26	0.00	332.00	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	21.45	9.49	0 00	347.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	22.00	9.41	0.00	329.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	22.15	9.42	0.00	327.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	22.30	9.41	0.00	337.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	22.45	9.38	0.00	340.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	23.00	9.28	0.00	357.50	0.01	0.09	0.04	0.00	0.09	0.05	0.05	0.08
1	23.15	9.90	5.12	256.00	10.53	8.77	9.22	10.06	8.09	9.0[illegible]	9.09	0.08
1	23.30	9.09	0.00	336.50	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	23.45	9.19	0.00	354.00	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
1	24.00	9.28	0.00	357.00	0.01	0.09	0.04	0.00	0.18	0.05	0.11	0.08
NEW DAY 11 OCT 72					ERTS-1 Chesapeake Bay Study Choptank River							
2	0.15	9.27	0.00	68.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	0.30	9.30	0.00	76.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	0.45	9.47	0.00	60.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	1.00	10.07	0.00	68.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	1.15	10.55	0.00	64.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	1.30	9.22	0.00	44.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	1.45	9.33	0.00	56.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	2.00	9.83	0.00	45.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	2.15	9.97	0.00	44.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	2.30	10.37	0.00	38.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	2.45	10.31	0.00	53.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	3.00	9.51	0.00	32.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	3.15	10.14	0.00	46.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	3.30	9.10	0.00	30.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	3.45	9.30	0.00	23.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	4.00	9.09	0.00	24.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	4.15	10.34	0.00	34.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	4.30	9.37	0.00	14.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	4.45	9.64	0.00	16.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	5.00	10.37	0.00	23.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	5.15	9.89	0.00	51.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	5.30	10.22	0.00	35.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	5.45	10.15	0.00	44.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	6.00	10.16	0.00	23.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	6.15	9.80	0.00	32.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	6.30	9.67	0.00	15.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	6.45	9.74	0.00	18.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	7.00	9.03	0.00	26.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	7.15	9.66	0.00	26.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	7.30	10.58	0.00	32.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	7.45	10.30	0.00	26.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	8.00	10.63	0.00	28.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	8.15	10.20	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	8.30	9.87	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	8.45	10.36	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	9.00	9.28	0.00	31.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	9.15	10.48	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	9.30	10.72	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	9.45	10.64	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	10.00	9.51	0.00	17.50	0.05	0.05	0.05	0.05	0.18	0.05	0.05	0.05
2	10.15	10.29	0.00	294.50	0.05	0.05	0.05	0.05	0.25	0.05	0.05	0.05
2	10.30	10.49	0.00	301.50	0.05	0.05	0.05	0.05	0.32	0.05	0.05	0.05
2	10.45	10.60	0.00	332.00	0.05	0.05	0.05	0.05	0.37	0.05	0.05	0.05
2	11.00	9.89	0.00	241.00	0.05	0.05	0.05	0.05	0.42	0.05	0.05	0.05
2	11.15	9.52	0.00	217.50	0.05	0.05	0.05	0.05	4.41	0.05	0.14	0.05
2	11.30	10.37	0.00	253.50	0.05	0.05	0.05	0.05	4.77	0.05	0.18	0.05
2	11.45	10.45	0.00	268.00	0.05	0.05	0.05	0.05	5.05	0.05	0.19	0.05
2	12.00	9.90	0.00	283.50	0.05	0.05	0.05	0.05	5.31	0.05	0.21	0.05
2	12.15	9.66	0.00	296.00	0.05	0.05	0.05	0.05	5.51	0.05	0.23	0.05
2	12.30	10.31	0.00	289.00	0.05	0.05	0.05	0.05	5.65	0.05	0.25	0.05

(Continued)

Table A2 (Concluded)

					Solar Radiation Cal/cm²/min							
Identification	Time hr/min	Wind Speed mph 0	Rain in. 1	Wind Direction Degrees 2	Filter 87C-UP 3	Filter 87C-DN 4	Filter 47-UP 5	Filter 47-DN 6	No Filter UP 7	No Filter DN* 8	Filter 29-UP* 9	Filter 29-DN 10
NEW DAY 11 OCT 72 (Continued)				ERTS-1 Chesapeake Bay Study Choptank River (Continued)								
2	12.45	9.01	0.00	289.50	0.05	0.05	0.05	0.05	5.77	0.05	0.25	0.05
2	13.00	9.88	0.00	237.50	0.05	0.05	0.05	0.05	0.62	0.05	0.26	0.05
2	13.15	10.72	0.00	218.00	0.05	0.05	0.05	0.05	0.64	0.05	0.25	0.05
2	13.30	10.13	0.00	217.50	0.05	0.05	0.05	0.05	0.62	0.05	0.23	0.05
2	13.45	9.79	0.00	172.50	0.05	0.05	0.05	0.05	0.60	0.05	0.23	0.05
2	14.00	10.53	0.00	255.00	0.05	0.05	0.05	0.05	0.58	0.05	0.21	0.05
2	14.15	9.28	0.00	216.00	0.05	0.05	0.05	0.05	0.57	0.05	0.19	0.05
2	14.30	9.44	0.00	277.50	0.05	0.05	0.05	0.05	0.55	0.05	0.18	0.05
2	14.45	10.07	0.00	231.00	0.05	0.05	0.05	0.05	0.51	0.05	0.16	0.05
2	15.00	10.75	0.00	250.00	0.05	0.05	0.05	0.05	0.41	0.05	0.05	0.05
2	15.15	10.24	0.00	251.00	0.05	0.05	0.05	0.05	0.19	0.05	0.05	0.05
2	15.30	10.59	0.00	244.50	0.05	0.05	0.05	0.05	0.21	0.05	0.05	0.05
2	15.45	9.14	0.00	237.00	0.05	0.05	0.05	0.05	0.11	0.05	0.05	0.05
2	16.00	9.29	0.00	234.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	16.15	9.36	0.00	235.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	16.30	10.58	0.00	225.00	0.05	0.05	0.05	0.05	0.14	0.05	0.05	0.05
2	16.45	9.19	0.00	240.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	17.00	10.74	0.00	216.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	17.15	9.25	0.00	224.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	17.30	10.75	0.00	209.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	17.45	9.73	0.00	219.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	18.00	9.15	0.00	213.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	18.15	10.09	0.00	213.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	18.30	9.51	0.00	220.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	18.45	10.09	0.00	196.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	19.00	9.57	0.00	217.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	19.15	9.87	0.00	198.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	19.30	9.70	0.00	177.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	19.45	9.57	0.00	190.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	20.00	9.76	0.00	155.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	20.15	9.05	0.00	160.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	20.30	10.74	0.00	125.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	20.45	10.06	0.00	116.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	21.00	9.55	0.00	47.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	21.15	9.94	0.00	52.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	21.30	10.43	0.00	48.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	21.45	10.65	0.00	69.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	22.00	10.18	0.00	95.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	22.15	10.20	0.00	90.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	22.30	10.61	0.00	101.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	22.45	9.01	0.00	116.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	23.00	10.37	0.00	84.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	23.15	9.53	0.00	86.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	23.30	10.01	0.00	129.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	23.45	9.60	0.00	125.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2	24.00	9.05	0.00	155.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

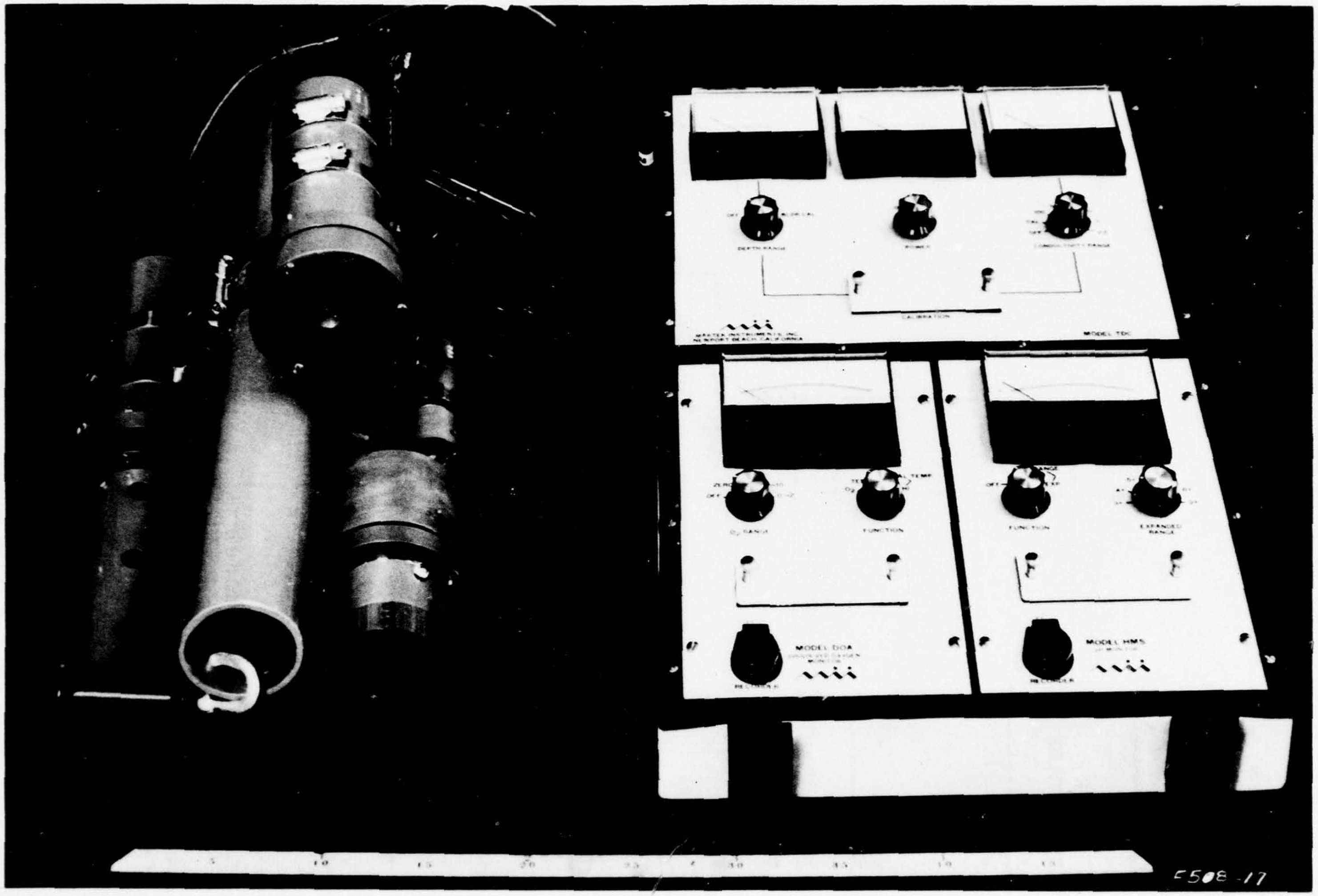


Figure A1. Water-quality monitoring system

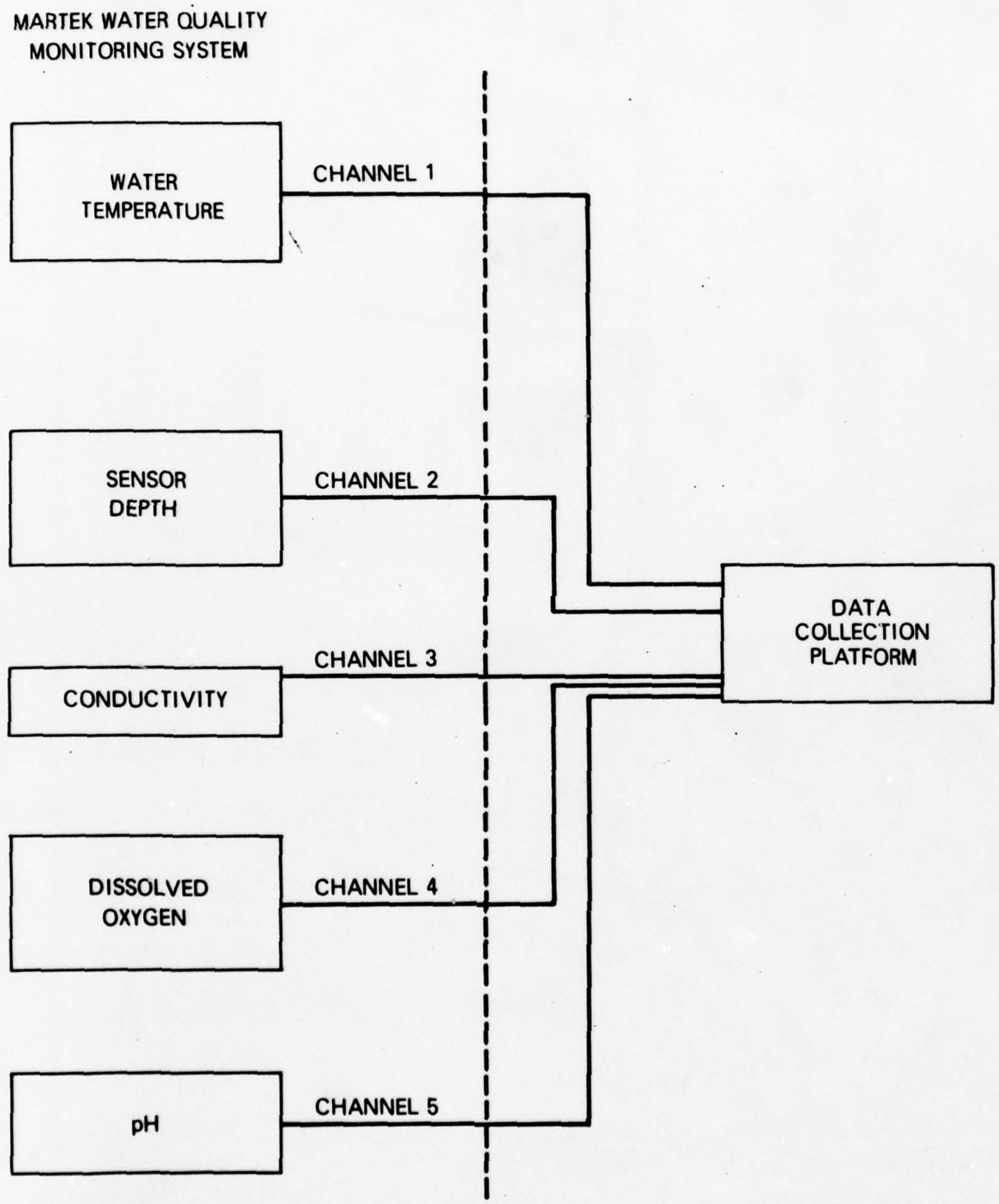


Figure A2. Interconnection of water-quality monitoring system and NASA Data Collection Platform

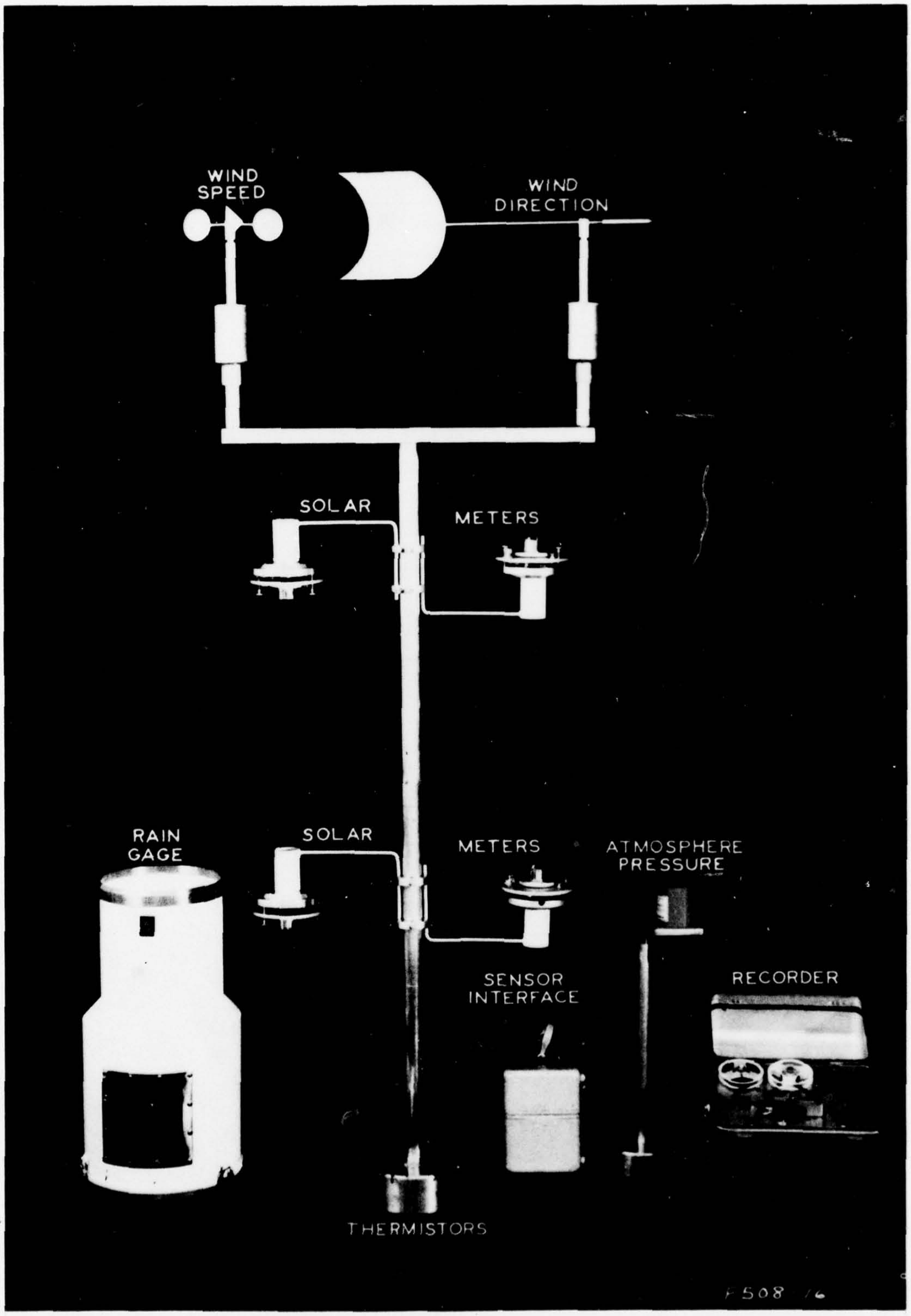


Figure A3. WES automated data collection system

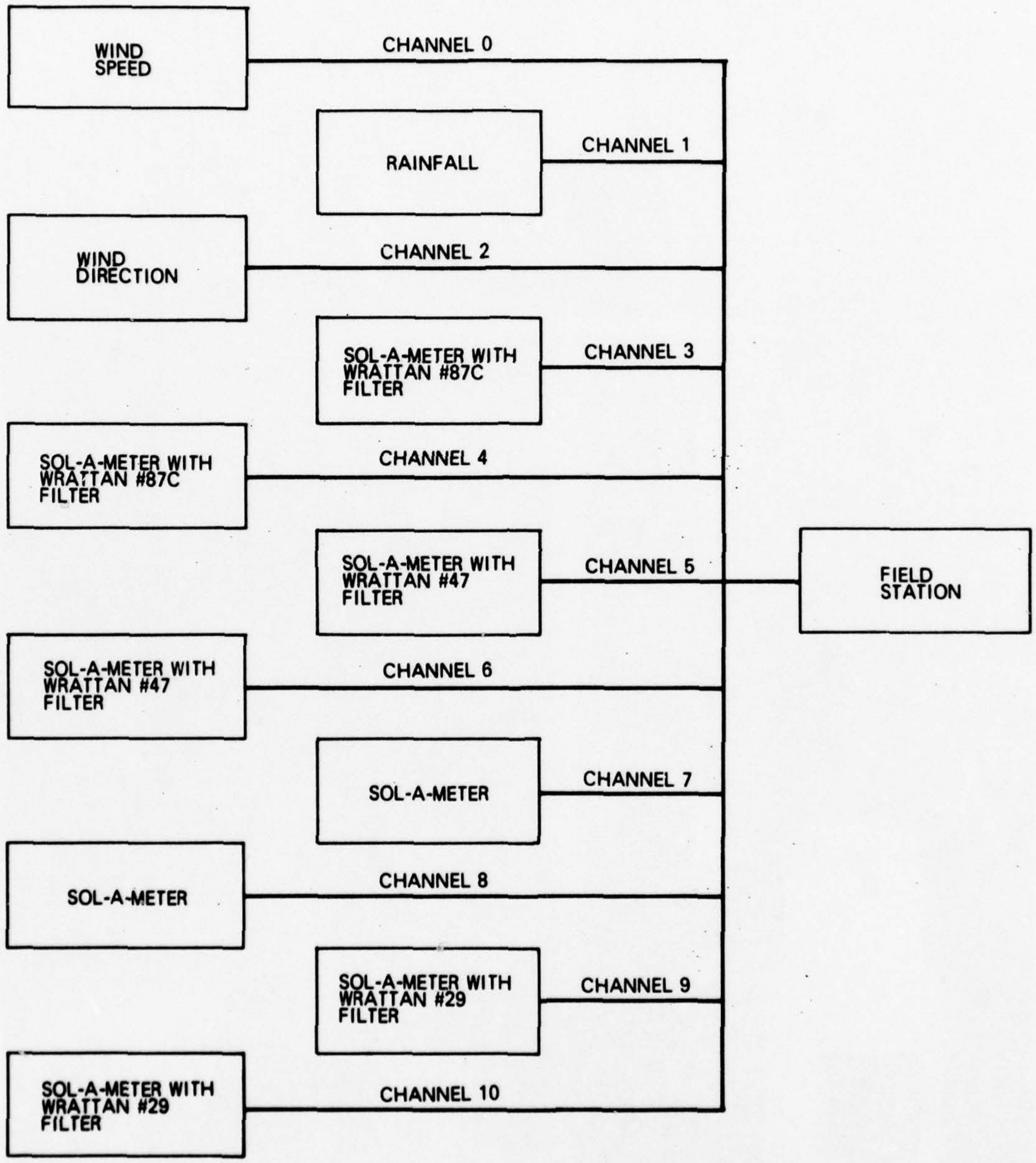


Figure A4. Schematic of WES automated data collection system

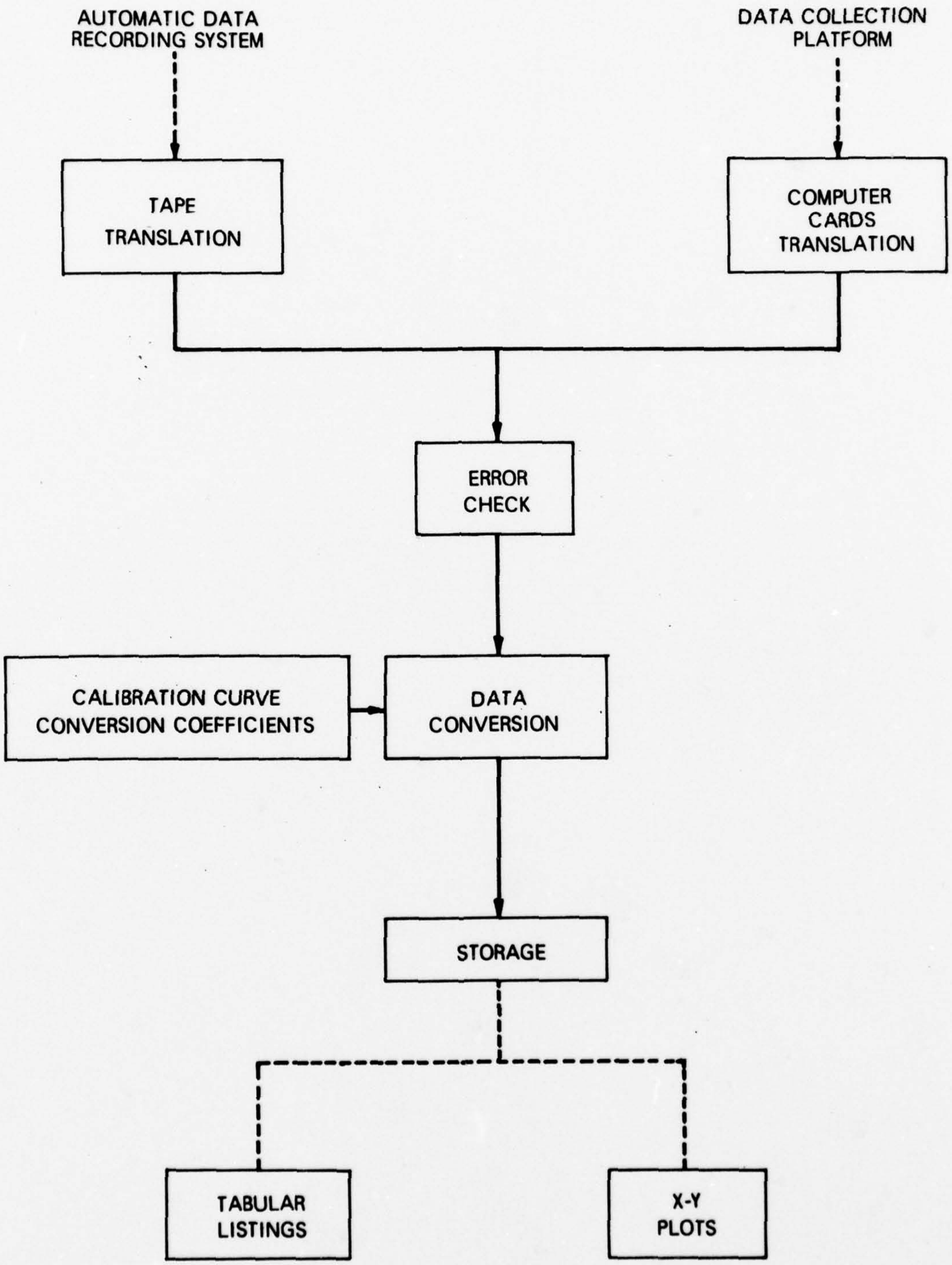


Figure A5. Flow diagram for automated data reduction

APPENDIX B: VALIDATION OF ALGORITHMS FOR HIGH SUSPENDED MATERIAL CONCENTRATIONS

Introduction

1. The algorithms developed at the U. S. Army Engineer Waterways Experiment Station for interpreting ERTS-1 multispectral scanner (MSS) data recorded on computer-compatible tapes (CCT's) were based on data from the two ERTS-1 scenes that together covered the Chesapeake Bay study area on 10 October 1972. The method proved useful for: (a) delineating areas of water on the earth's surface; (b) observing the effects of varying concentrations of suspended material on the radiance measurements of MSS bands 4, 5, and 6; (c) classifying water pixels in terms of suspended material concentrations on the basis of band-4, -5, and -6 radiance values; and (d) producing maps of the water that show areas having similar concentrations of suspended materials.

2. Unfortunately, concentrations of suspended materials in the Chesapeake Bay area were almost always less than 60 mg/ℓ, thus giving rise to the question of the applicability of the algorithms when higher concentrations are present.

Purpose

3. The purpose of the work discussed in this appendix was to determine the validity of the data processing algorithms when suspended material concentrations are greater than 60 mg/ℓ and to compare data for one area (Choptank River) under different tidal cycles.

Scope

4. Three study areas were selected for this study--a portion of Cook Inlet, Alaska, Lake Pontchartrain, Louisiana, and the Choptank River. The data reduction and interpretation process developed in connection with the initial study of portions of the Chesapeake Bay area was exploited and the results were converted to suspended material distribution photomaps.

Cook Inlet

5. Cook Inlet was selected because the suspended material concentration was known to be high and ground control data were available from other agencies that were conducting studies in the area. The region is characterized by cloudiness and haze over much of the area most of the time. Therefore, care was taken to select an ERTS-1 scene of the area that contained minimum haze and cloud cover and still coincided as nearly as possible in time with ground control data collection. In view of these considerations, ERTS-1 scene No. 1266-20581 (15 April 1973) was selected. Ground control data taken by Dr. F. Wright, University of Alaska, on 14 April 1973 were available from the U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

6. An image of scene No. 1266-20581 is shown in Figure B1. Table B1 includes ground control data for Cook Inlet for 14 April 1973. The ground control data were taken at intervals along a line between the entrance to Chinitna Bay and Homer Spit at the entrance to Kachomak Bay (Figure B2). In Figure B1, much of the northeastern, southeastern, and central portions of the scene are totally obscured by haze and clouds. Inspection of Table B1 reveals that the highest concentrations of suspended material were at sites 7-13. However, in Figure B1, it appears that some of these sites may have been obscured from satellite view by the clouds. Sites 7, 9, and 13 exhibited unusually high radiance values (Table B2), probably as a result of cloud reflections, and were therefore eliminated from consideration in establishing sediment concentration classes.

7. In view of the objectives of this study, the suspended material concentrations determined from water samples taken at the various ground control data collection sites were disappointingly low. However, higher concentrations of material were known to occur in the Inlet, particularly in the northern end. The regression line in Figure B3 was therefore extrapolated beyond the maximum concentration found at the ground control data collection sites to 140 mg/ℓ (Figure B4). Suspended material concentration ranges were then established using the extrapolated

correlations of radiance and suspended material concentration. The resulting classes are given in Table B3.

8. The suspended material distribution photomap, resulting from writing a film using these classifications is shown in Figure B5. Unusually large portions of the Inlet are unclassified in this photomap. In addition, a number of small areas where a low concentration of suspended material is indicated are located near areas of comparable size and similar shape having high suspended material concentrations (such as in circle A, Figure B5). This suggests that some clouds may have been classified as high suspended material concentration areas and the shadows they cast on the water may have been classified as low suspended material concentration areas.

9. The large areal extent of unclassified areas and the many occurrences of what appear to be clouds and shadows make this photomap especially difficult to interpret for distribution of suspended material concentrations. This leads to the conclusion that the correlations of radiance and suspended material concentrations may have been seriously affected by the general distribution of haze and clouds over the area.

Lake Pontchartrain

10. During the 1973 flood of the Lower Mississippi River Valley, the Bonnet Carré Floodway connecting the Mississippi River with Lake Pontchartrain near New Orleans, Louisiana, was opened. The waters that flowed into Lake Pontchartrain as a result were heavy-laden with suspended materials. Since this large influx of material could impact on the fishing and transportation industries that rely on Lake Pontchartrain, the New Orleans District, Corps of Engineers, implemented a sampling program in Lake Pontchartrain in which suspended material and water-quality samples were taken at a large number of points on an almost daily basis.

11. The fact that ground control data would be available, plus the fact that suspended material concentrations would be high, prompted selection of Lake Pontchartrain for this study. The ERTS-1 scene that

was selected (No. 1285-16024) provided a view of conditions in the Lake that existed on 4 May 1973, approximately one month after the floodway was first opened.

12. Ground control data were not taken in Lake Pontchartrain on the day of the overpass, but were taken at 20 sites (Figure B6) on 3 May 1973 and again at some sites on 6 May 1973. It was therefore necessary to interpolate, where possible, to find the suspended material concentrations on the day of the satellite overpass. The ground control data and the results of interpolations are shown in Tables B1 and B2.

13. Unfortunately, many of the ground control data collection stations were located near the shoreline and/or in shallow water where spectral characteristics would not necessarily be related to the concentration of suspended materials. Therefore, with the aid of nautical charts, each station was evaluated in terms of the probability that adverse affects on MSS measurements might result from shallow water or impure pixels (pixels whose band 4, 5, and 6 values may be affected by the combination of land and water), and those stations having a high probability of providing erroneous correlative data were rejected. The results of this evaluation are given in Table B4.

14. Graphs of radiance versus suspended material concentration were then plotted (Figure B7). The correlations of radiance and suspended material concentration were not clearly apparent when the data for all six "accepted" stations were considered. The data for stations 3, 11, and 17 appeared to be unrelated to suspended material concentration and were subsequently rejected.

15. On the basis of data for the three remaining stations--4, 5, and 12--correlations of radiance and suspended material concentrations and classifications of suspended material concentrations (Table B3) were established. The result of converting the classifications to a sediment distribution photomap is shown in Figure B8.

16. It is interesting to note that final classification could be made on the correlation of radiance and suspended material concentration at only three ground control data collection stations. However, these stations, located near the Lake Pontchartrain Causeway (black north-south

line through the center of Lake Pontchartrain in Figure B6), provided a high correlation coefficient in the regression analysis. The poor correlation of data taken at stations 3, 11, and 17 may have been the result of ground control data for these stations being interpolated rather than being taken at the time of satellite overpass.

17. The unclassified areas within the high-concentration plume along the south side of the lake (Figure B8) are probably the result of a distribution of algae over these portions of the lake.

Choptank River

18. A spring 1973 examination of the Chesapeake Bay study area as viewed by ERTS-1 was a part of the initial study of this area and was planned in order to assess the influence of tides on detection of suspended material concentrations. However, adverse weather conditions prevailed and, after several postponements, 14 May 1973 was finally established as the last opportunity to gather ground control data. On this date the Choptank River was the only area in the Chesapeake Bay study area that was not at least partially obscured from satellite view (Figure B9).

19. Ground control data were taken at the sites indicated in Figure B10. Some of these sites are the same as those selected for the initial study of the area. Sites 1A, 1B, 1E, 1F, 3A, 3B, 5A, and 5B were selected in an attempt to define spectrally the types of material flowing into the Choptank River.

20. Ground control data (Table B1) show the suspended material concentration to be between 7.5 and 20.9 mg/ℓ. However, from the correlation of radiance and suspended material concentration (Figure B11), separation of suspended material concentration classes is difficult. As in the basic study, the radiance values appear to vary independently of suspended material concentration except for one horizontal trend line composed of stations 3A, 3B, 5A, and 1B. However, when a deliberate search was made for data points that trend along straight lines, two groups emerge--stations 1, 1E, and 1F (which is called population 1

in Figure B11) and stations 1, 1E, 6, 8, and 9 (which is called population 2 in Figure B12). These sets yielded moderately high regression coefficients except for band 6, population 1 (Figure B11), which has a regression coefficient of 0.15 and band 4, population 2 (Figure B12) which has a regression coefficient of 0.52. However, the suspended material distribution photomaps (Figures B13 and B14) indicate, as they did in the basic study, that these populations coexist everywhere in the estuary--an impossible condition.

21. Figure B13 shows the suspended material distribution as being somewhat different from that shown in Figure B14, but there is little semblance of reality apparent in either population 1 or 2. It is highly unlikely that an estuarine system as complex as the Choptank River will have a homogeneous suspended material concentration over almost the entire area of the estuary. This condition is particularly suspect in view of the complexity of the pattern of distribution shown in the suspended material distribution photomap produced with data from the 10 October 1972 ERTS-1 overpass of the area.

22. A more reasonable explanation for the apparent homogeneity of suspended materials can be derived from consideration of weather conditions in the study area. The Choptank River was entirely surrounded by clouds of sufficient density to obscure the area from view. If the Choptank River had been covered by a layer of haze (which is a reasonable assumption), the solar radiation passing through the haze would have been transmitted, absorbed, and/or scattered in a manner depending on the wavelength, and a portion of the solar radiation would have been backscattered from the top side of the haze layer. The net effect of this would be: (a) diminution of spectral information from the water as a result of the wavelength-dependent reduction of solar radiation as it penetrated the haze layer; (b) unusual constancy of radiance values regardless of known differences in suspended material concentration as a result of diffuse backscatter; and (c) erroneous classification of suspended material concentrations.

Conclusions

23. The following conclusions are based on the study reported in this appendix:

<u>a</u>. Adverse effects of clouds and haze may partially or totally negate the effectiveness of the data interpretation process used herein.

<u>b</u>. Only a limited number of good-quality ground control samples are required to establish good correlations of radiance in MSS bands 4, 5, and 6 with suspended material concentration.

<u>c</u>. The quantity of material being carried in suspension does not appear to have any adverse effects on the usefulness of the data interpretation algorithms, when material concentrations are less than about 350 mg/ℓ (the maximum concentration in this study).

Recommendations

24. On the basis of the foregoing, the following recommendations are made:

<u>a</u>. Studies be undertaken to increase understanding of the impact of haze and clouds on multispectral scanner detection of terrain attributes and to produce a usable method for countering these adverse effects.

<u>b</u>. The validity of the algorithms for mapping suspended material concentration be tested for concentrations in excess of 350 mg/ℓ.

<u>c</u>. Algorithms be developed to correctly identify clouds and the shadows they cast.

Table B1

Ground Control Data

Station No.	Date	Time Hours	Suspended Material Concentration mg/ℓ	Secchi Depth m	Cloud Cover Percent	Water Sample Depth m
			Cook Inlet, Alaska			
1	14 Apr 73	0750	1.695		Data not available	
2		0809	1.745			
3		0823	1.205			
4		0900	1.415			
5		0932	2.060			
6		1030	2.870			
7		1102	10.315			
8		1134	16.425			
9		1315	43.740			
10		1355	48.795			
11		1426	34.030			
12		1458	22.575			
13		1536	9.130			
14		1600	5.550			
15		1700	2.200			
16		1758	2.685			
17		1850	1.440			
18		1940	1.160			
			Lake Pontchartrain, Louisiana			
(1) 05001	3 May 73	1005	383	Data not available		1.22
	4 May 73		343*			
	6 May 73	1015	262			1.22
(2) 05002	3 May 73	1020	146			0.91
	4 May 73		165*			
	6 May 73	1025	204			0.91
(3) 05003	3 May 73	0915	112			2.44
	4 May 73		112*			
	6 May 73	0920	111			2.44

(Continued)

Note: Numbers in parenthesis preceding station numbers correspond to data points in Plate A6.

* Denotes interpolated values.

(Sheet 1 of 3)

Table B1 (Continued)

Station No.	Date	Time Hours	Suspended Material Concentration mg/ℓ	Secchi Depth m	Cloud Cover Percent	Water Sample Depth m
Lake Pontchartrain, Louisiana (Continued)						
(4) 05004	3 May 73	1540	210	Data not available		2.74
	4 May 73		176*			
	6 May 73	1605	109			2.74
(5) 05005	3 May 73	1450	147			2.44
	4 May 73		155*			
	6 May 73	1505	171			2.44
(6) 05006	3 May 73	0952	164			2.44
	4 May 73					
(7) 05007	3 May 73	0930	169			2.44
	4 May 73					
(8) 85739	3 May 73	1100±	93			3.81
	4 May 73					
(9) 85702	3 May 73	1100±	96			3.81
	4 May 73					
(10) 85624	3 May 73	1625	58			1.83
	4 May 73		62*			
	6 May 73	1650	70			1.52
(11) 85613	3 May 73	1605	156			2.13
	4 May 73		131*			
	6 May 73	1630	82			2.13
(12) 85600	3 May 73	1510	151			2.74
	4 May 73		152*			
	6 May 73	1535	155			2.74
(13) 85614	3 May 73	1330	128			1.83
	4 May 73		159*			
	6 May 73	1350	221			2.13

(Continued)

* Denotes interpolated values.

Table B1 (Concluded)

Station No.	Date	Time Hours	Suspended Material Concentration mg/ℓ	Secchi Depth m	Cloud Cover Percent	Water Sample Depth m
			Lake Pontchartrain, Louisiana (Continued)			
(14) 85615	3 May 73	1250	104	Data not available		1.22
	4 May 73		119*			
	6 May 73	1315	150			2.13
(15) 85430	3 May 73	1145	149			1.22
	4 May 73		136*			
	6 May 73	1200	111			1.83
(16) 85617	3 May 73	1115	113			1.52
	4 May 73		114*			
	6 May 73	1140	115			1.52
(17) 85618	3 May 73	0940	120			2.13
	4 May 73		126*			
	6 May 73	0940	137			2.44
(18) 85641	3 May 73	0840	63			2.13
	4 May 73		91*			
	6 May 73	0845	148			2.13
(19) 76060	3 May 73	1650	66			2.13
	4 May 73					
(20) 85750	3 May 73	>1200	95			
	4 May 73					
			Choptank River and Vicinity			
1	14 May 73	1040	9.2	2.0	40	Data not available
1A		1128	19.1	3.0	30	
1B		1138	15.6	2.5	30	
1E		1050	19.2	2.0	40	
1F		1030	20.9	2.0	50	
3A		1214	7.5	2.5	20	
3B		1235	10.9	3.0	20	
5		1010	13.6	2.5	50	
5A		0955	13.9	1.3	60	
5B		1000	8.2	1.5	60	
6		1313	15.2	2.0	15	
8		1331	9.8	2.5	15	
9		1338	13.2	1.5	20	
10		1345	11.9	1.0	20	

* Denotes interpolated values.

(Sheet 3 of 3)

Table B2

Correlation of Radiance Values With Suspended Material Concentrations

Station No.	Suspended Material Concentration mg/ℓ	Radiance, mW/cm^2-sr MSS Band 4	5	6
Cook Inlet, Alaska				
1	1.695	0.99	0.40	0.20
2	1.745	1.02	0.40	0.22
3	1.205	0.99	0.33	0.22
4	1.415	0.96	0.40	0.22
5	2.060	0.96	0.40	0.22
6	2.870	1.27	0.46	0.24
7	10.315	1.50	0.84	0.65
8	16.425	1.39	0.67	0.34
9	43.740	3.24	2.36	2.09
10	48.795	1.45	0.84	0.45
11	34.030	1.39	0.71	0.38
12	22.575	1.39	0.69	0.35
13	9.130	1.50	0.84	0.54
14	5.550	1.19	0.46	0.24
15	2.200	0.96	0.40	0.24
16	2.685	1.02	0.40	0.22
17	1.440	1.19	0.42	0.22
18	1.160	1.13	0.42	0.26
Lake Pontchartrain, Louisiana				
(1) 05001	343*	1.54	1.01	1.52
(2) 05002	165*	1.36	0.67	1.52
(3) 05003	112*	1.59	0.76	1.23
(4) 05004	176*	1.82	1.26	0.98
(5) 05005	155*	1.71	1.18	0.69
(6) 05006	164	1.76	1.26	0.82
(7) 05007	169	1.82	1.26	0.82
(8) 85739	93	1.76	1.22	0.73
(9) 85702	96	1.71	1.18	0.78
(10) 85624	62*	1.71	1.26	0.94

(Continued)

Note: Numbers in parentheses preceeding Station No. corresponds to data points in Figure B7.

* Interpolated value.

Table B2 (Concluded)

Station No.	Suspended Material Concentration mg/ℓ	Radiance, mW/cm^2-sr MSS Band 4	5	6
Lake Pontchartrain, Louisiana (Continued)				
(11) 85613	131*	1.82	1.31	0.90
(12) 85600	152*	1.76	1.18	0.90
(13) 85614	159*	1.71	1.22	0.94
(14) 85615	119*	1.76	1.31	0.90
(15) 85430	136*	1.76	1.35	0.98
(16) 85617	114*	1.76	1.26	0.98
(17) 85618	126*	1.36	0.63	1.39
(18) 85641	91*	1.31	0.67	1.06
(19) 76060	66	1.76	1.18	0.82
(20) 85750	95	1.71	1.22	0.78
Choptank River and Vicinity				
1	9.2	1.54	0.76	0.49
1A	19.1	1.59	0.80	0.49
1B	15.6	1.65	0.88	0.61
1E	19.2	1.59	0.88	0.61
1F	20.9	1.59	0.84	0.45
3A	7.5	1.65	0.88	0.61
3B	10.9	1.65	0.84	0.61
5	13.6	1.54	0.76	0.45
5A	13.9	1.65	0.88	0.61
5B	8.2	1.59	0.80	0.57
6	15.2	1.59	0.84	0.53
8	9.8	1.59	0.80	0.53
9	13.2	1.59	0.88	0.61
10	11.9	1.54	0.84	0.53

* Interpolated value.

Table B3

Summary of Suspended Material Concentration Classes

Class	Suspended Material Concentration Ranges mg/ℓ	Radiance, mW/cm^2-sr MSS Bands 4	5	6
		Cook Inlet, Alaska		
1	0-17	0.97-1.26 (17-22)	0.30-0.59 (7-14)	0-0.25 (0-6)
2	17-40	1.14-1.48 (20-26)	0.51-0.85 (12-20)	0.16-0.41 (4-10)
3	40-100	1.43-2.11 (25-37)	0.76-1.44 (18-34)	0.29-0.74 (7-18)
4	>100	>2.05 (36-63)	>1.31 (31-63)	>0.66 (16-63)
		Lake Pontchartrain, Louisiana		
1	<150	1.54-1.77 (27-31)	0.89-1.19 (21-28)	0-0.82 (0-20)
2	150-165	1.65-1.83 (29-32)	1.10-1.27 (26-30)	0.70-0.95 (17-23)
3	165-180	1.71-1.88 (30-33)	1.19-1.31 (28-31)	0.86-1.07 (21-26)
4	>180	>1.76 (31-63)	>1.27 (30-63)	1.03-1.23 (25-30)
		Choptank River and Vicinity (No. 1)		
1	0-12.5	1.43-1.60 (25-28)	0.68-0.89 (16-21)	0.41-0.58 (10-14)
2	12.5-25.0	1.54-1.71 (27-30)	0.76-1.02 (18-24)	0.49-0.70 (12-17)
3	>25.0	>1.65 (29-63)	>0.85 (20-63)	>0.62 (15-63)
		Choptank River and Vicinity (No. 2)		
1	0-15	1.43-1.60 (25-28)	0.64-0.85 (15-20)	0.45-0.58 (11-14)
2	15-30	1.54-1.71 (27-30)	0.72-1.02 (17-24)	0.49-0.62 (12-15)
3	>30	>1.65 (29-63)	>0.85 (20-63)	>0.58 (14-63)

Table B4

Evaluation of Reliability of Radiance Values at Data Collection Stations, Lake Pontchartrain, Louisiana

Station No.	Accepted	Rejected	Reason for Rejection
1		x	Shallow water
2		x	Shallow water
3	x		
4	x		
5	x		
6		x	Shallow water
7		x	Shallow water
8		x	"Impure" pixel
9		x	"Impure" pixel
10		x	Shallow water
11	x		
12	x		
13		x	Shallow water
14		x	Shallow water
15		x	"Impure" pixel
16		x	Shallow water
17	x		
18		x	Shallow water
19		x	"Impure" pixel
20		x	"Impure" pixel

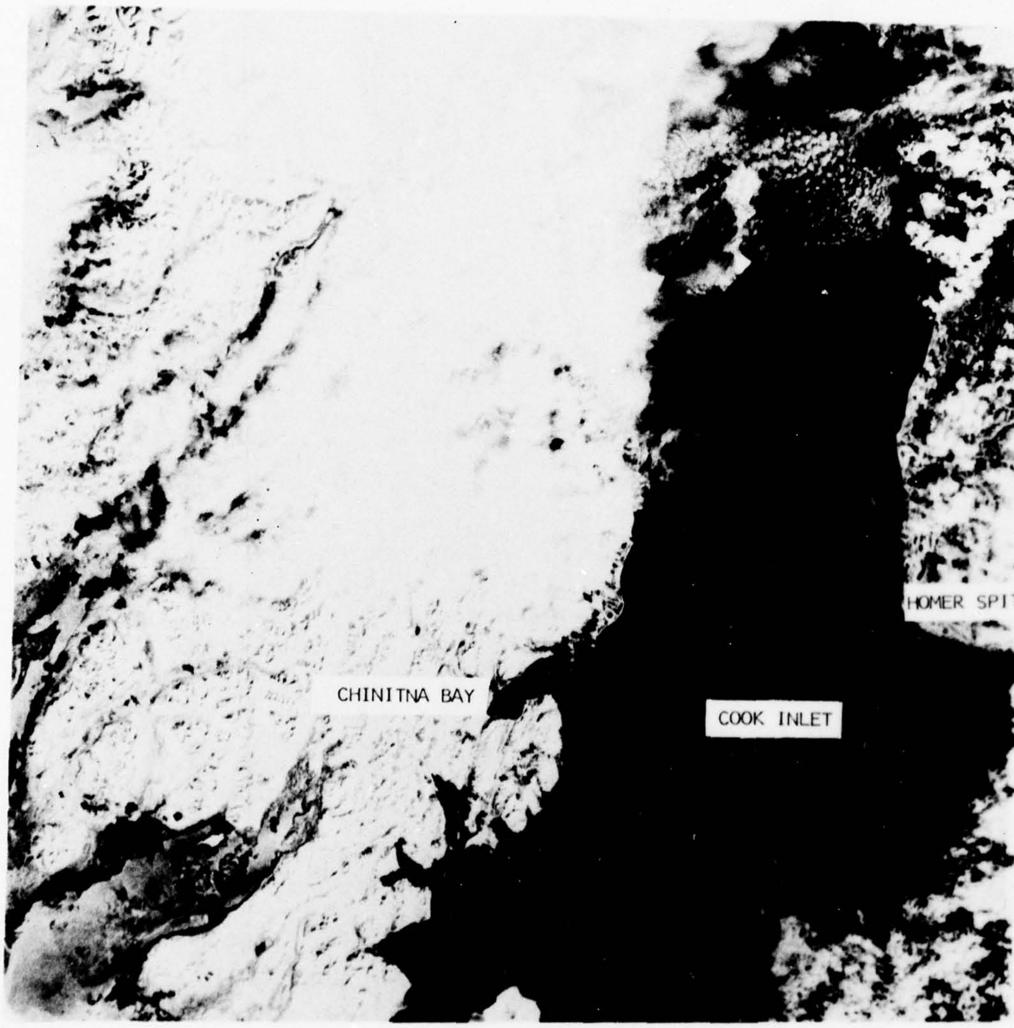


Figure B1. Cook Inlet, Alaska, as seen by ERTS-1 MSS band 6 (0.7 to 0.8 μm)

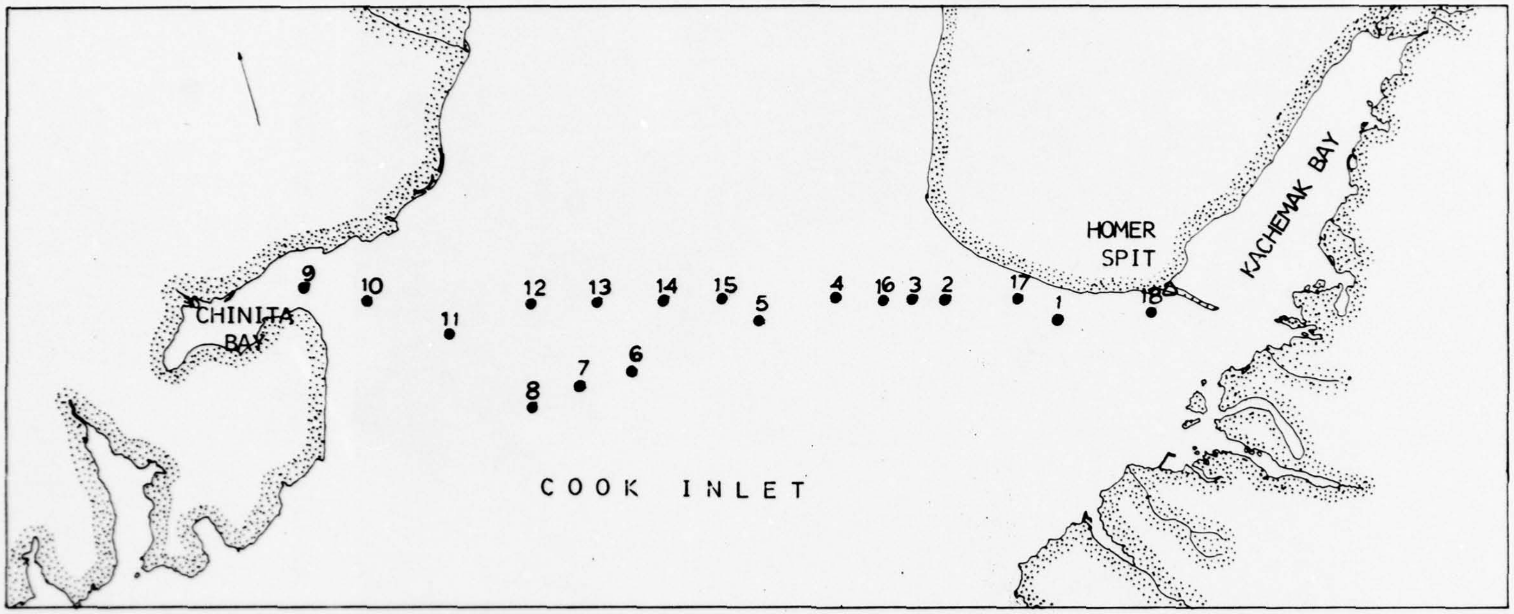


Figure B2. Locations of ground control data collection stations--Cook Inlet

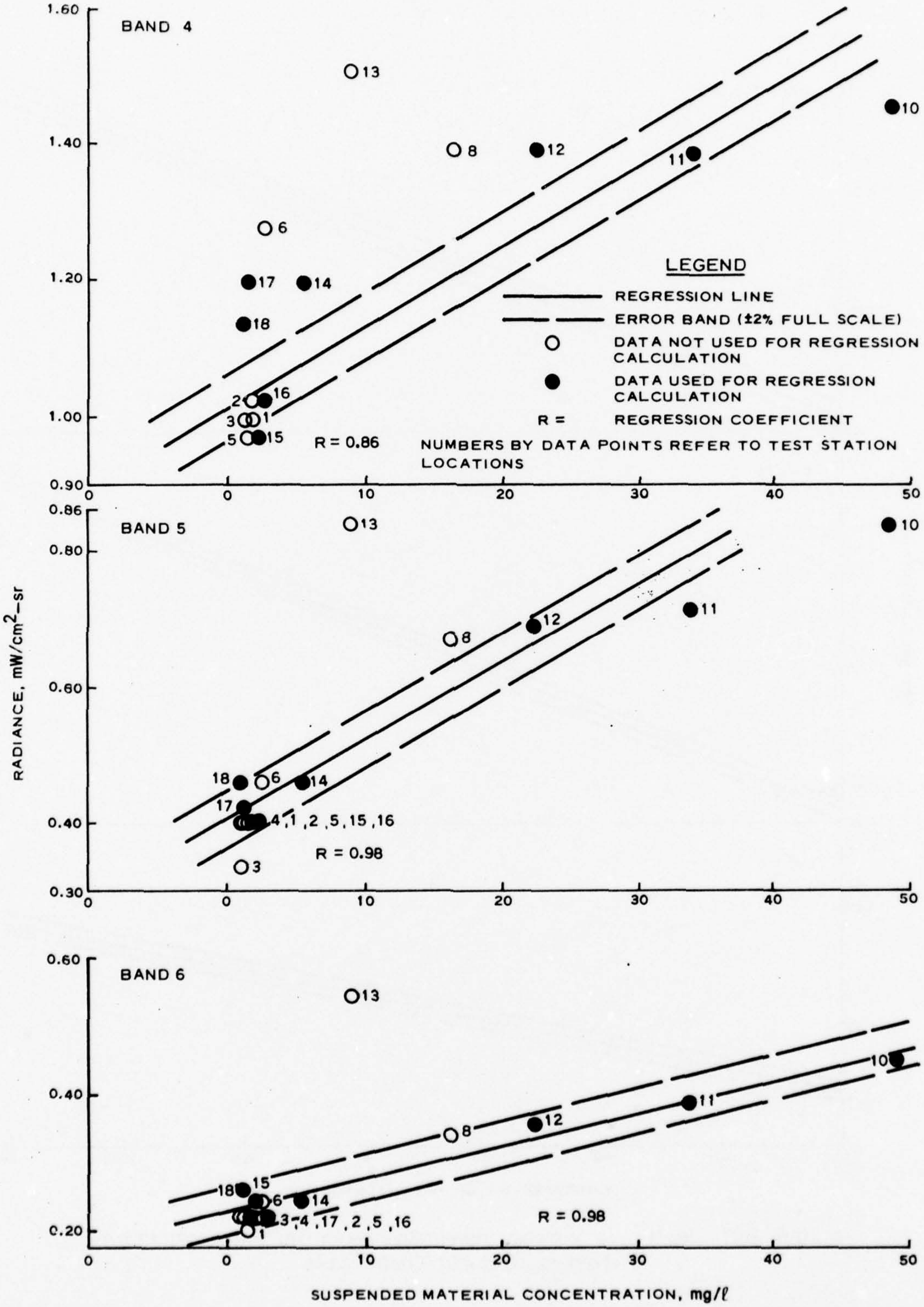


Figure B3. Radiance versus suspended material concentration, Cook Inlet, Alaska

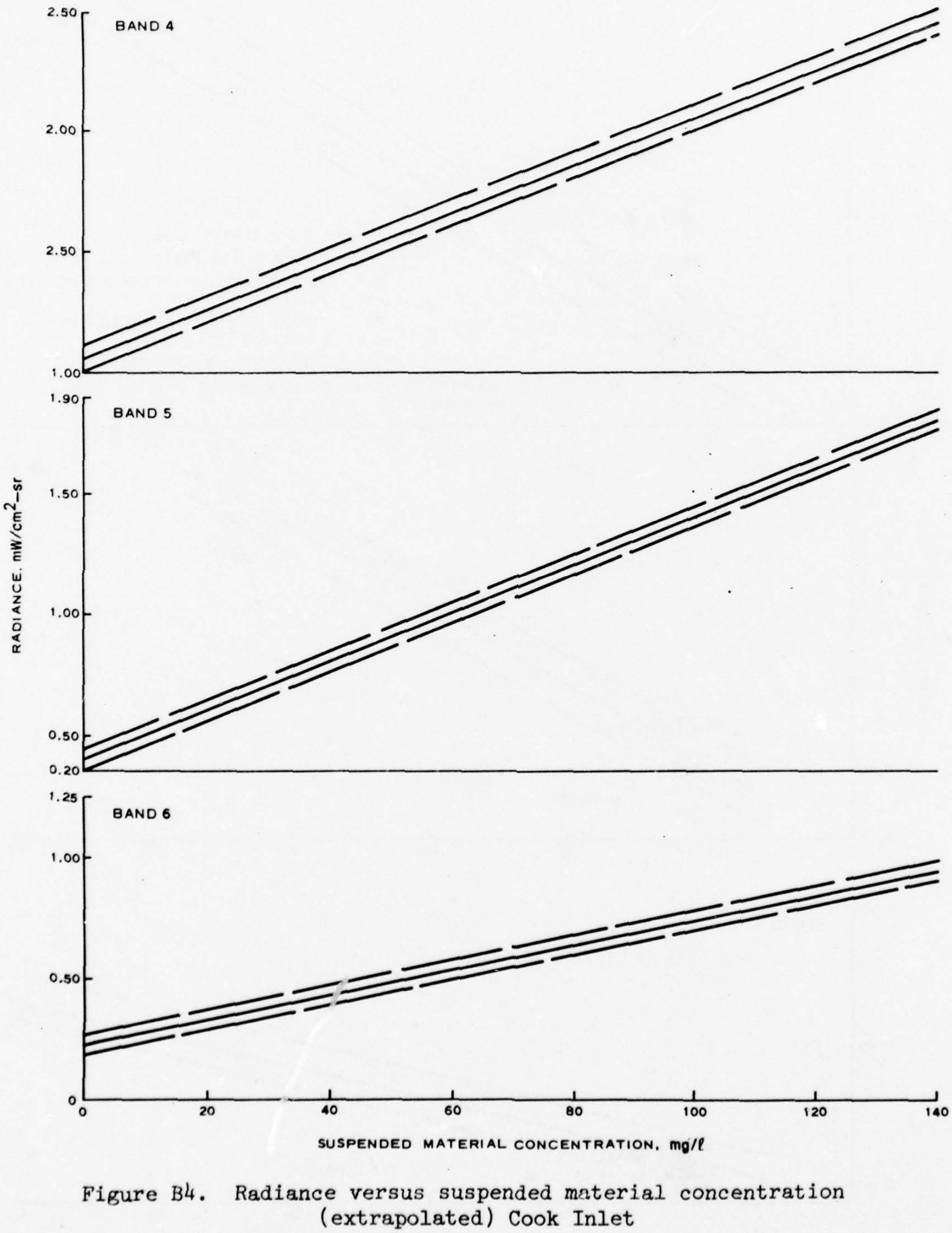


Figure B4. Radiance versus suspended material concentration (extrapolated) Cook Inlet

Figure B5. Suspended material distribution photomap, Cook Inlet, Alaska

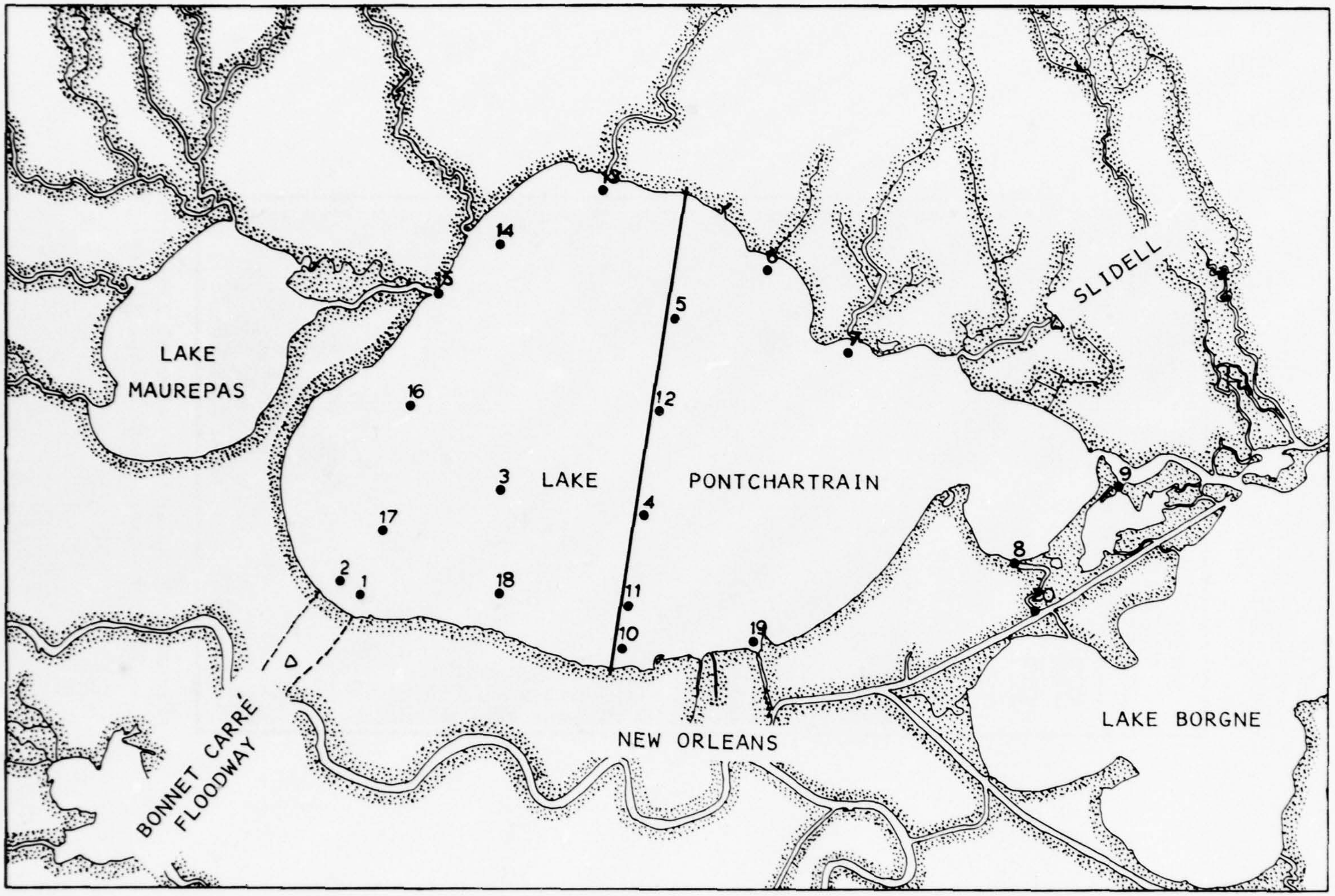


Figure B6. Locations of ground control data collection stations-Lake Pontchartrain

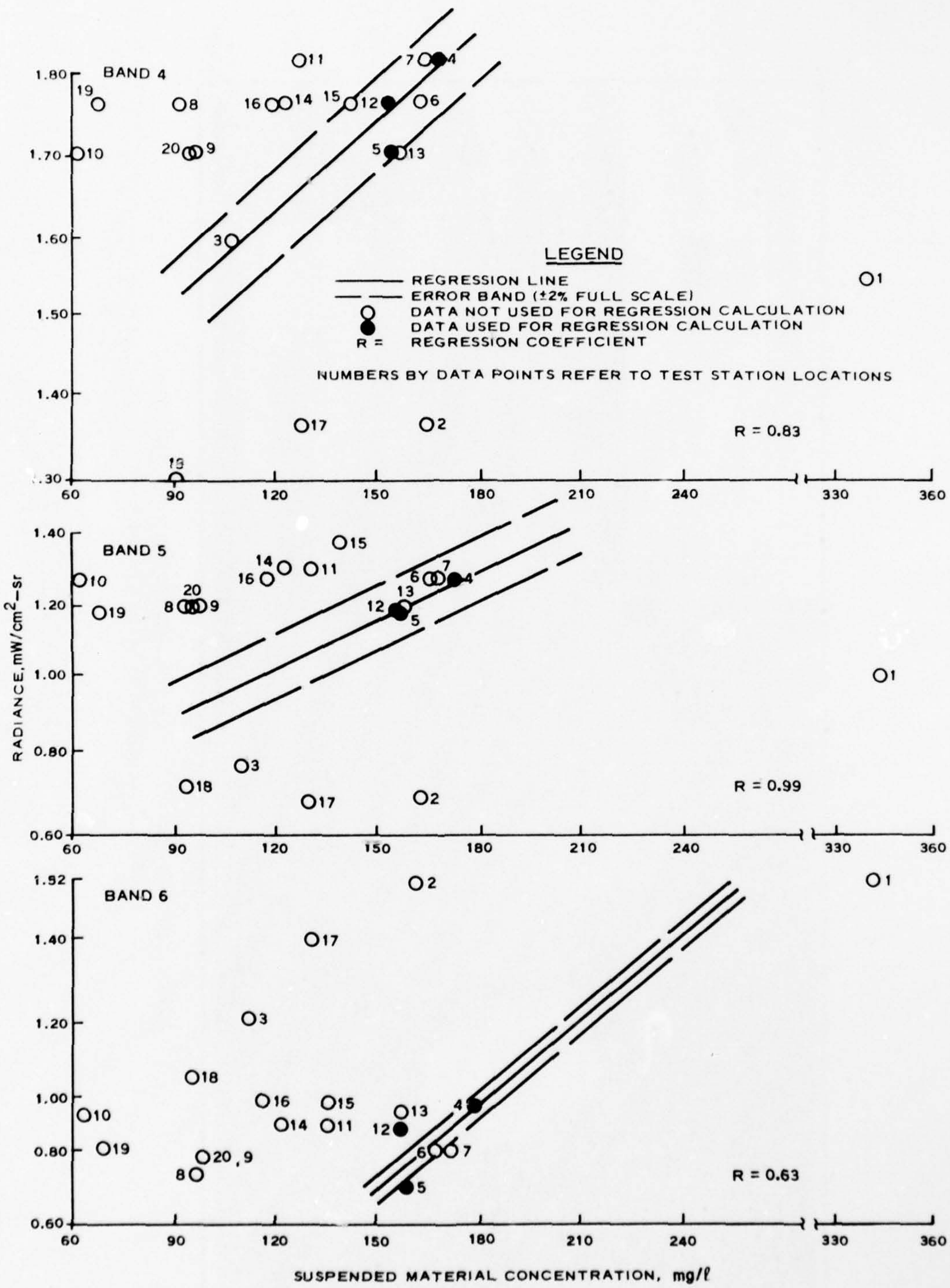


Figure B7. Radiance versus suspended material concentration, Lake Pontchartrain, Louisiana

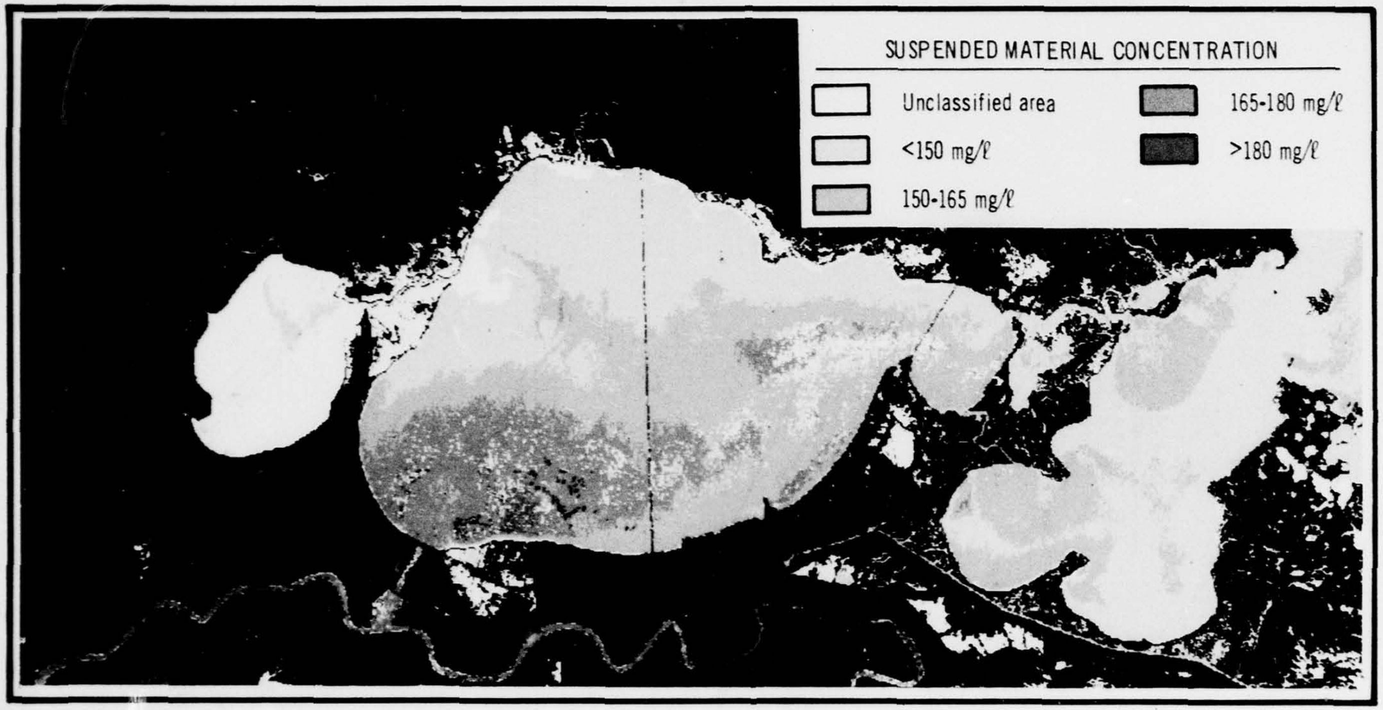


Figure B8. Suspended material distribution photomap, Lake Pontchartrain, Louisiana

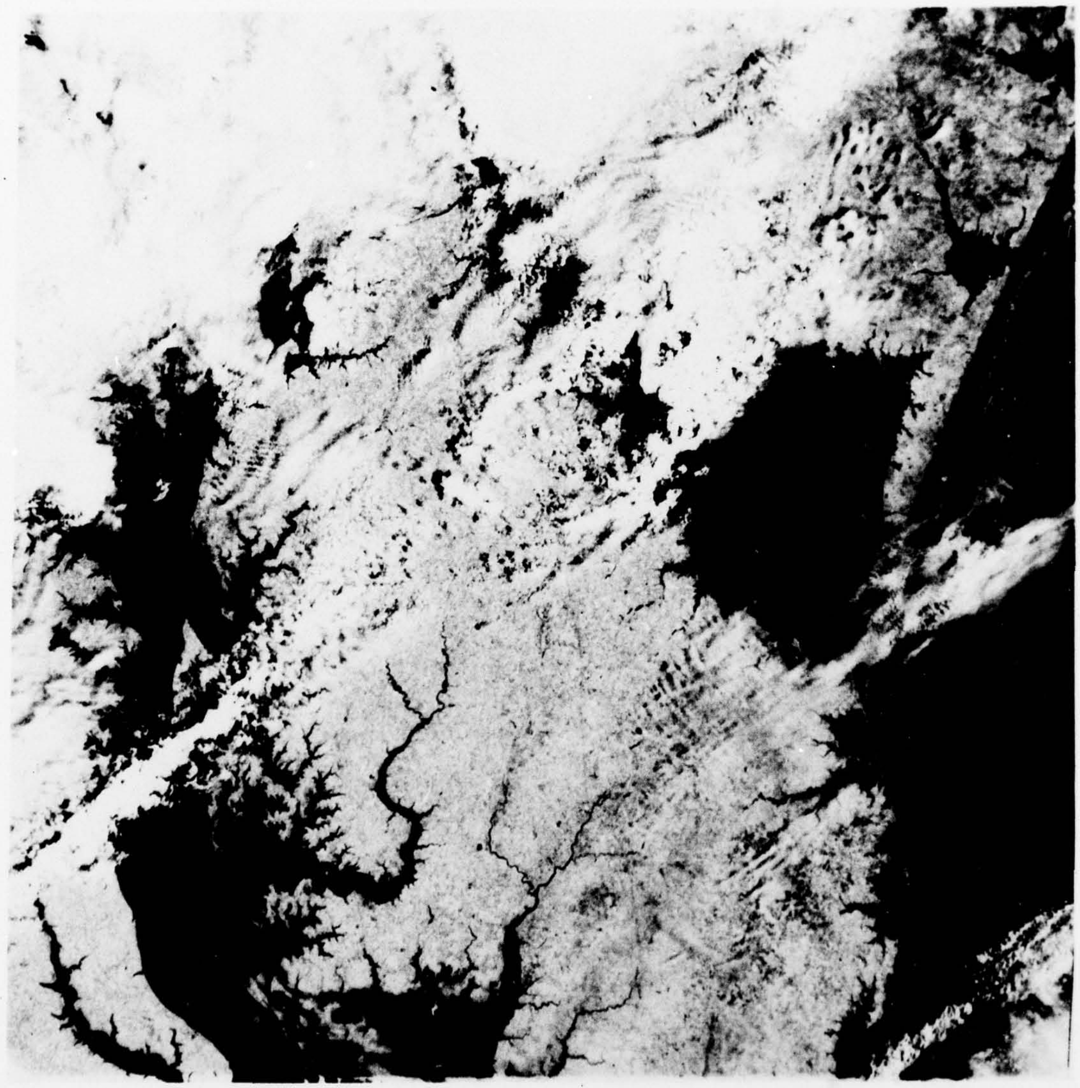


Figure B9. Choptank River and vicinity as viewed by ERTS-1 MSS band 7 (0.8 to 1.1 μm)

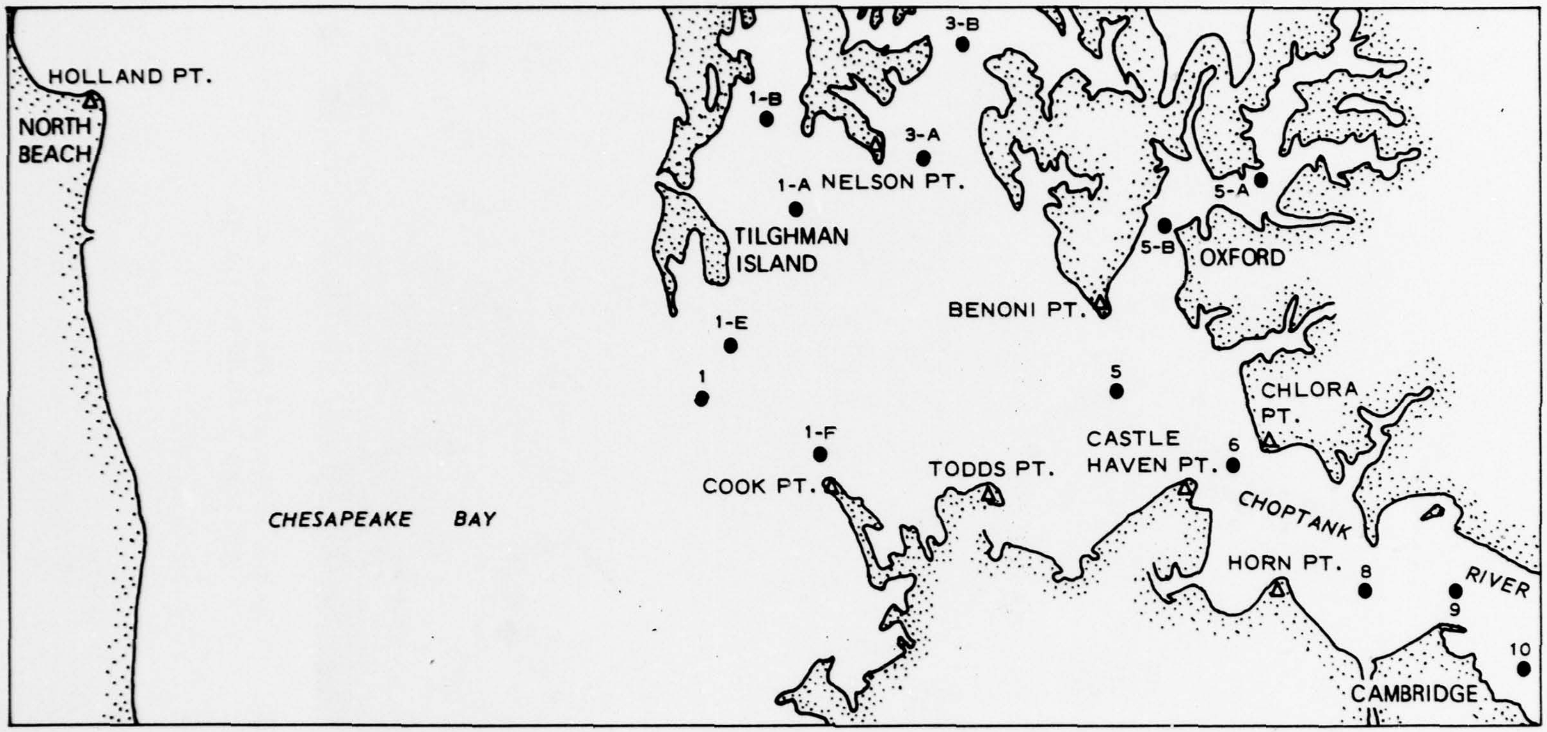


Figure B10. Location of ground control data collection stations, Choptank River, 14 May 1973

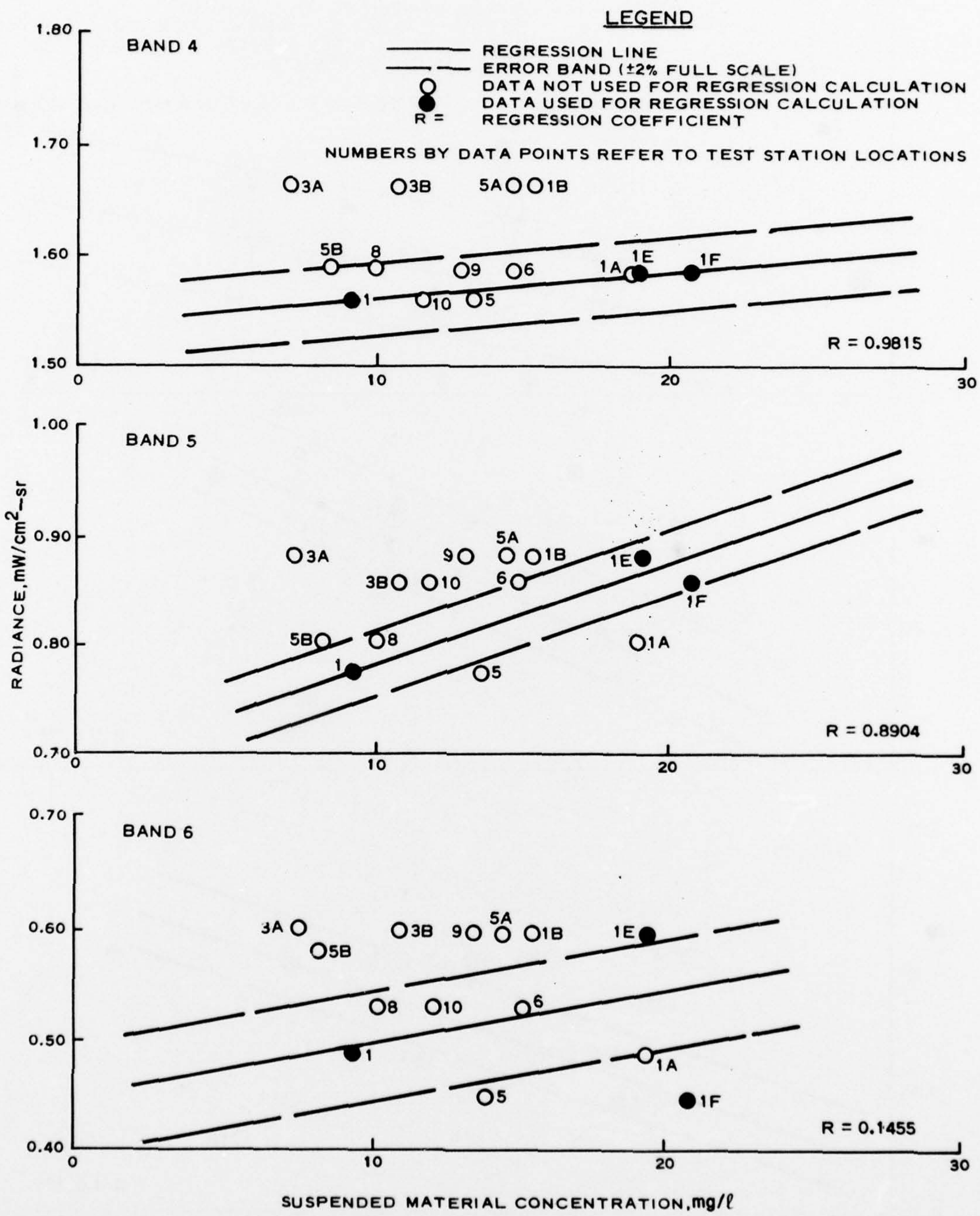


Figure B11. Radiance versus suspended material concentration, Choptank River (population 1)

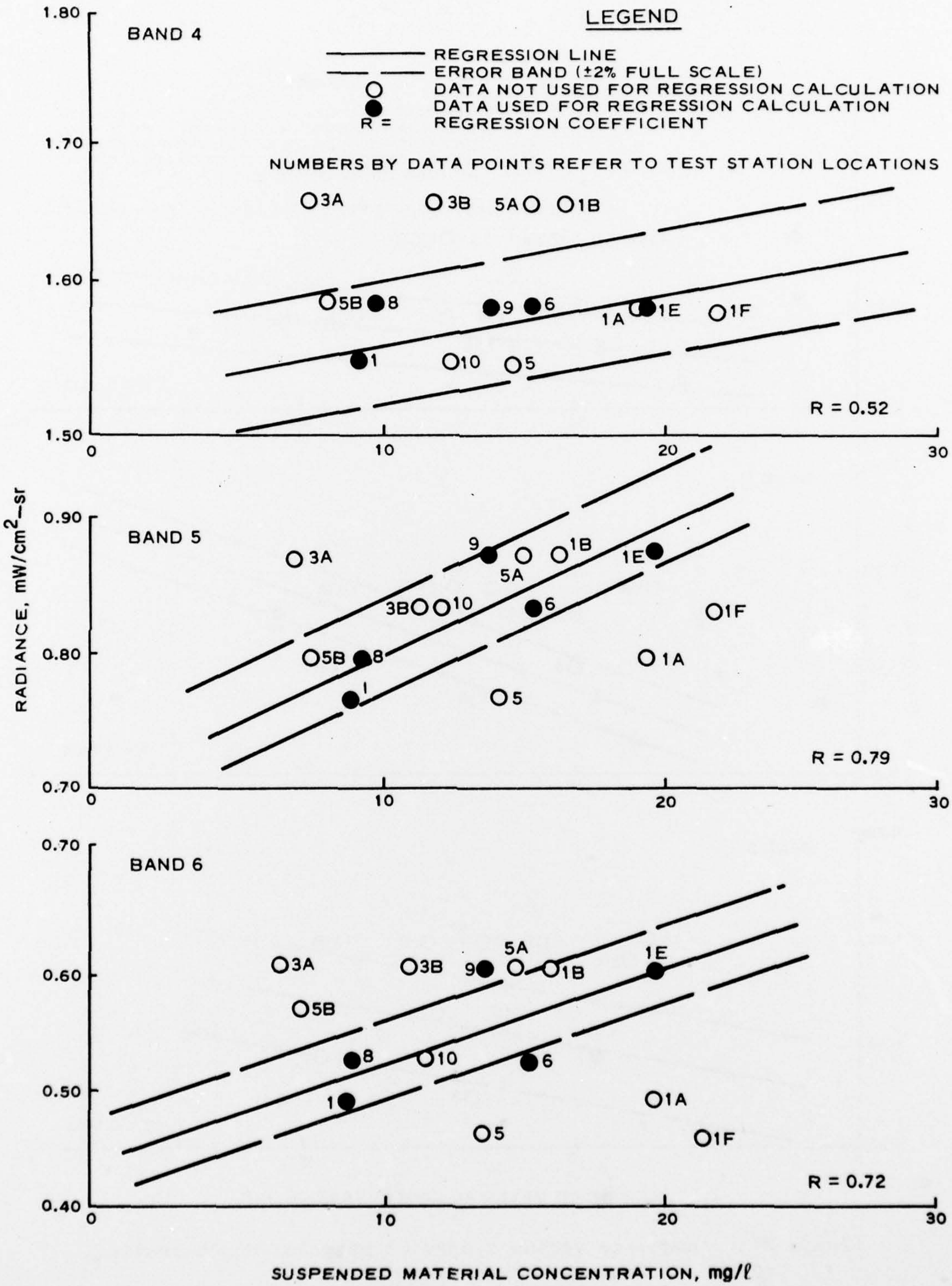


Figure B12. Radiance versus suspended material concentration, Choptank River (population 2)

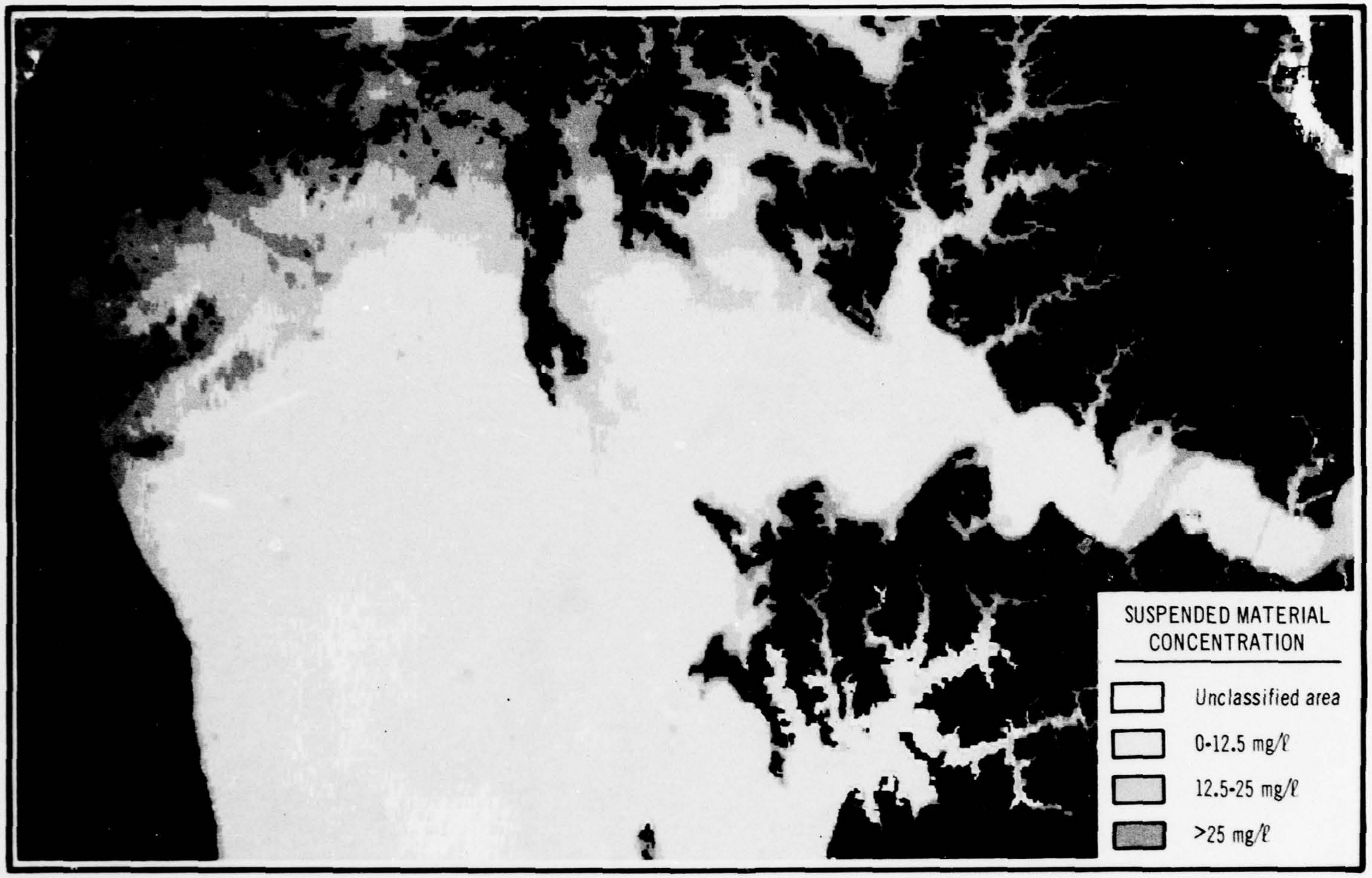


Figure B13. Sediment distribution photomap, Choptank River and adjoining portion of Chesapeake Bay (population 1)

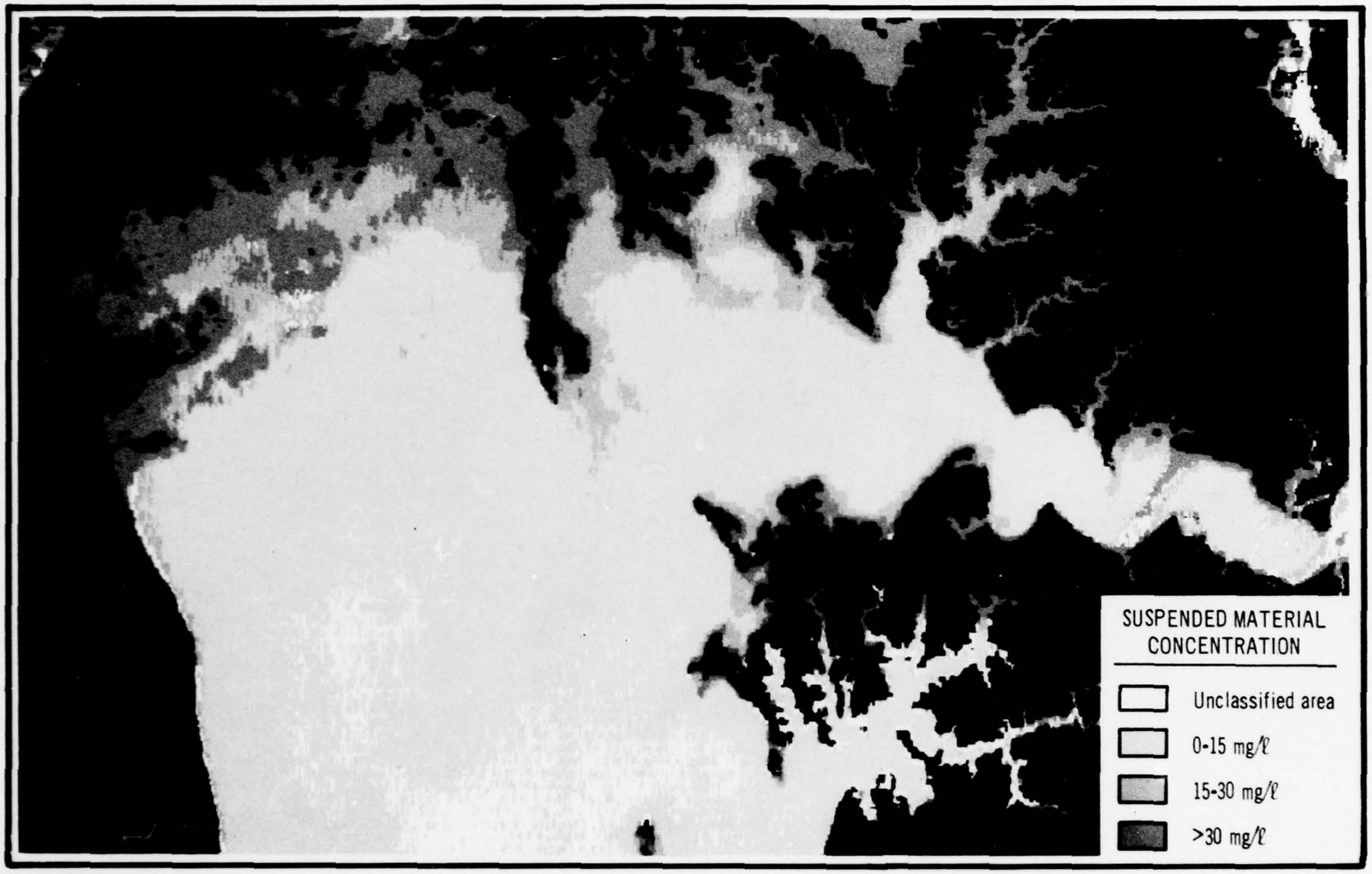


Figure B14. Sediment distribution photomap, Choptank River and adjoining portion of Chesapeake Bay (population 2)

APPENDIX C: BY-PRODUCTS OF THE STUDIES OF THE CHESAPEAKE BAY AREA

1. The ability to process ERTS-1 computer-compatible tapes, which was developed in connection with the Chesapeake Bay study discussed in the main text, has found extensive use in two areas of interest to the U. S. Army Corps of Engineers. One was the National Dam Safety Program, in which the Corps of Engineers was required to produce inventories of water bodies in the United States, and the other area was that of mapping the areal extent of flooding in the Lower Mississippi River Valley during the 1973 flood.

Reservoir Inventory

2. The reservoir inventory (Figure C1) is a list that identifies every discrete open-water surface detected by ERTS-1 by latitude and longitude, and gives an estimate of its water surface area. A computer program that is referred to as the contiguity routine was used to produce the inventory. In the contiguity routine, data for the first ERTS-1 scan line are placed in computer memory as a line of "zeros" and "ones" corresponding to land and water pixels, as in Figure C2. Each individual water pixel is placed in a separate file on disk, so that in the example, pixel 1-3 (line 1, pixel number 3) is in one file, pixel 1-7 is in another file, and so on. Scan line 2 is then placed in memory and a search routine is initiated. All pixel locations occupied by "zeros" are passed over, since they pertain to land. However, the discovery of a "one" in pixel 2-6 initiates a search routine:

Step	Question	Response	Action
1	Is pixel 1-5 a 1	No	Go to step 2
2	Is pixel 1-6 a 1	No	Go to step 3
3	Is pixel 1-7 a 1	Yes	Place pixel 2-6 in the same file as pixel 1-7; go to pixel 2-7 and resume search

The effect of this routine is to assemble a separate file for each group of contiguous pixels.

3. Upon completion of the search of scan line 2, scan line 1 is dropped from memory and scan line 3 is placed in memory (Figure C3). The search routine will detect the fact that the files holding pixels 2-6 and 2-10 are connected by a line of contiguous pixels in line 3. When this occurs, the two files are consolidated into a new file on the disk. After all scan lines have been searched, the disk contains a separate file for each water body, and the number of entries is equivalent to the number of pixels, which in turn can be used to calculate an approximate surface area. This process required 1-2 hr of computer time per ERTS-1 scene depending on the number of water bodies in the scene.

4. The latitude and longitude that appear on the inventory list is the position of the pixel at the midpoint of the longest line of pixels in the file representing the water body (Figure C4). Latitudes and longitudes in the list are referenced to the latitudes and longitudes of the four corners of the ERTS-1 scene. The estimate of surface area is based on the area of each pixel being 1.1 acres.

Flood Maps of the Lower Mississippi River Valley

5. Production of flood maps of the Lower Mississippi River Valley was based on the strong absorption by water of electromagnetic radiation in the 0.8-1.1 μm band and the fact that this resulted in a clear separation of land and water in band-7 radiance measurements.

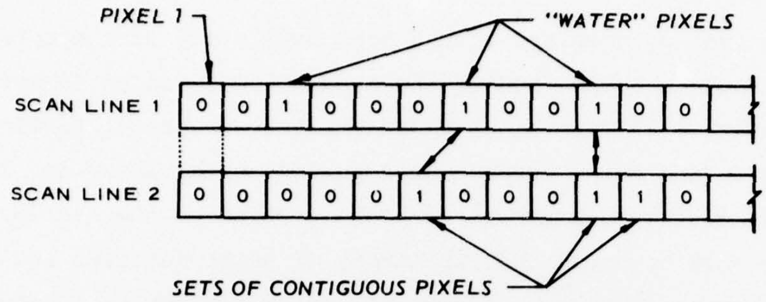
6. Band-7 data were scanned on a pixel-by-pixel basis, and all pixels with values less than 0.20 mW/cm^2-sr (this value was as high as 0.90 mW/cm^2-sr when hazy conditions existed over the scene area) were identified as water pixels. A computer tape was produced with pixels identified by a "one" (water) or a "zero" (land). A film writer was then used to convert all "one" pixels to a maximum exposure on photographic film, and all "zero" pixels were not given an exposure. In the process of enlarging this negative to map scale (1:250,000), all water areas become transparent on a piece of film acetate and land areas are black, as shown in Figure C5.

7. This type of overlay, when placed over a map of the corresponding area, provides a comparison of the area not covered by forest, that was inundated by flood waters, as shown by the transparent portion of the overlay with the water surface area during normal low-water levels as seen on the map through the transparent portion of the overlay.

8. It should be noted that the areas of water detected and mapped are only open-water surfaces, and not all areas subject to inundation. Those areas that were inundated but forested were not mapped, since the radiance data in such areas were derived from the forest canopy and not the water surface. The "water vs land" algorithm interprets such areas as land.

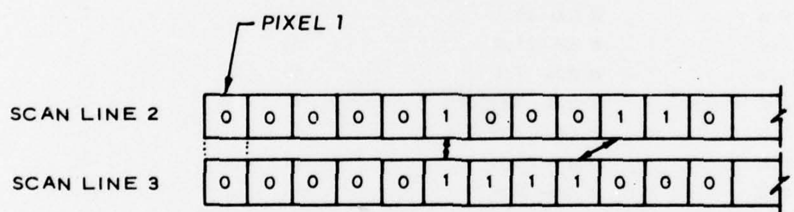
LATITUDE DEG MIN	LONGITUDE DEG MIN	PIXEL COUNT	EST. SURFACE ACRES
N35- 9.6	W 82-21.4	45.	50.
N35- 7.0	W 82- 4.8	1.	1.
N35- 9.2	W 82-18.9	2.	2.
N35- 9.6	W 82-21.7	1.	1.
N35- 9.8	W 82-21.9	3.	3.
N35- 6.3	W 82- 1.1	1.	1.
N35- 6.2	W 82- 1.0	1.	1.
N35- 9.5	W 82-21.9	1.	1.
N35- 8.8	W 82-17.8	2.	2.
N35- 6.2	W 82- 0.8	19.	21.
N35- 9.4	W 82-21.9	6.	7.
N35- 6.2	W 82- 1.8	2.	2.
N35- 6.1	W 82- 1.3	27.	30.
N35- 9.4	W 82-22.1	1.	1.
N35- 6.0	W 82- 0.7	10.	11.
N35- 6.7	W 82- 5.3	1.	1.

Figure C1. Sample printout of inventory of surface water bodies



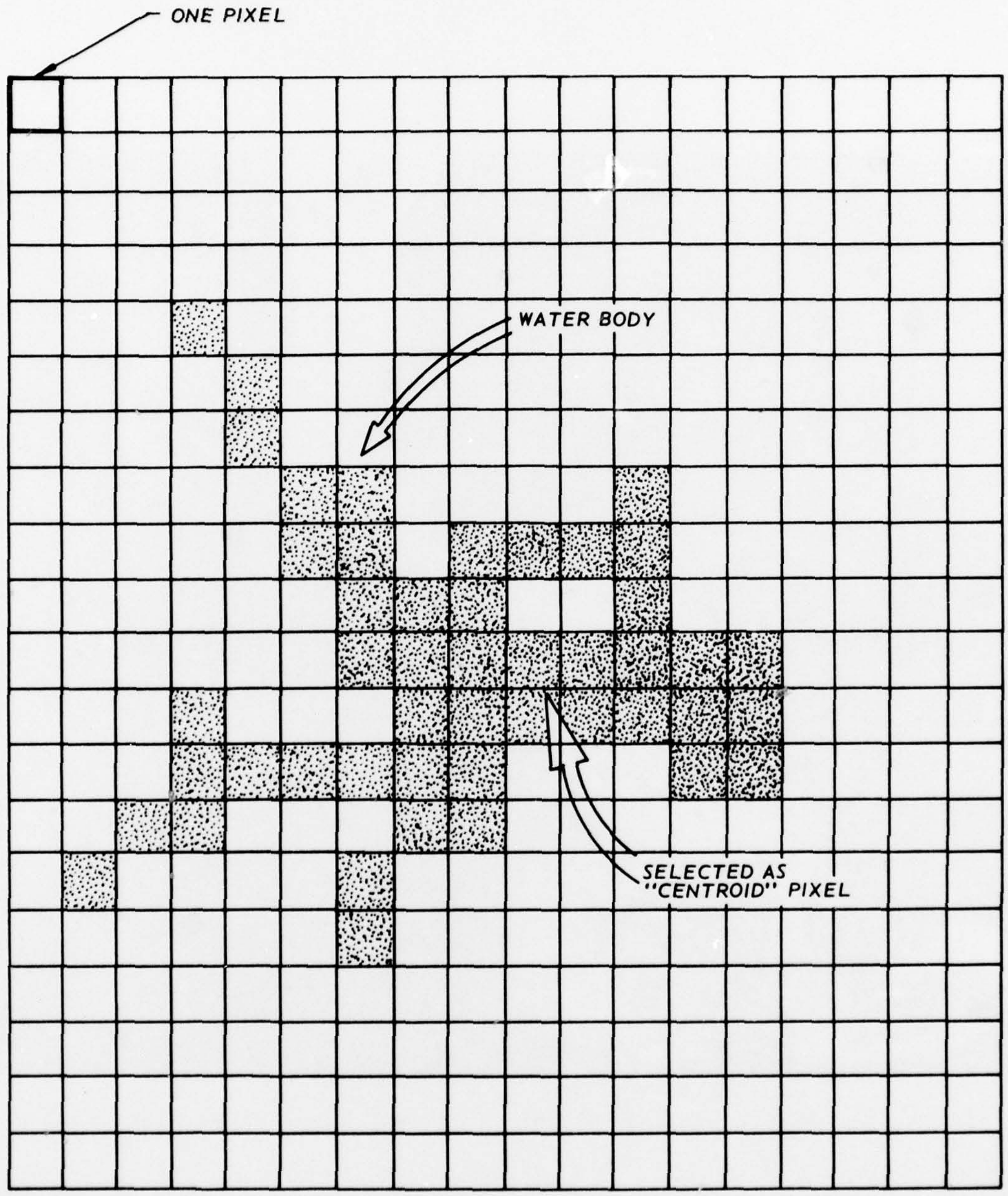
FILES ESTABLISHED FOR SCAN LINE 1	FILE A 1-3	FILE B 1-7	FILE C 1-10
FILES AFTER SEARCH OF SCAN LINE 2	FILE A 1-3	FILE B 1-7 2-6	FILE C 1-10 2-10 2-11

Figure C2. The contiguity rule



STATUS OF FILES AFTER SEARCH OF SCAN LINE 2	FILE A 1-3	FILE B 1-7 2-6	FILE C 1-10 2-10 2-11	
STATUS OF FILES AFTER SEARCH OF SCAN LINE 3	FILE A 1-3	FILE B	FILE C	FILE D 1-7 1-10 2-6 2-10 2-11 3-6 3-7 3-8 3-9

Figure C3. File consolidation



LATITUDE AND LONGITUDE OF WATER BODY
SPECIFIED BY LOCATION OF "CENTROID" PIXEL

Figure C4. Selection of "centroid" pixel

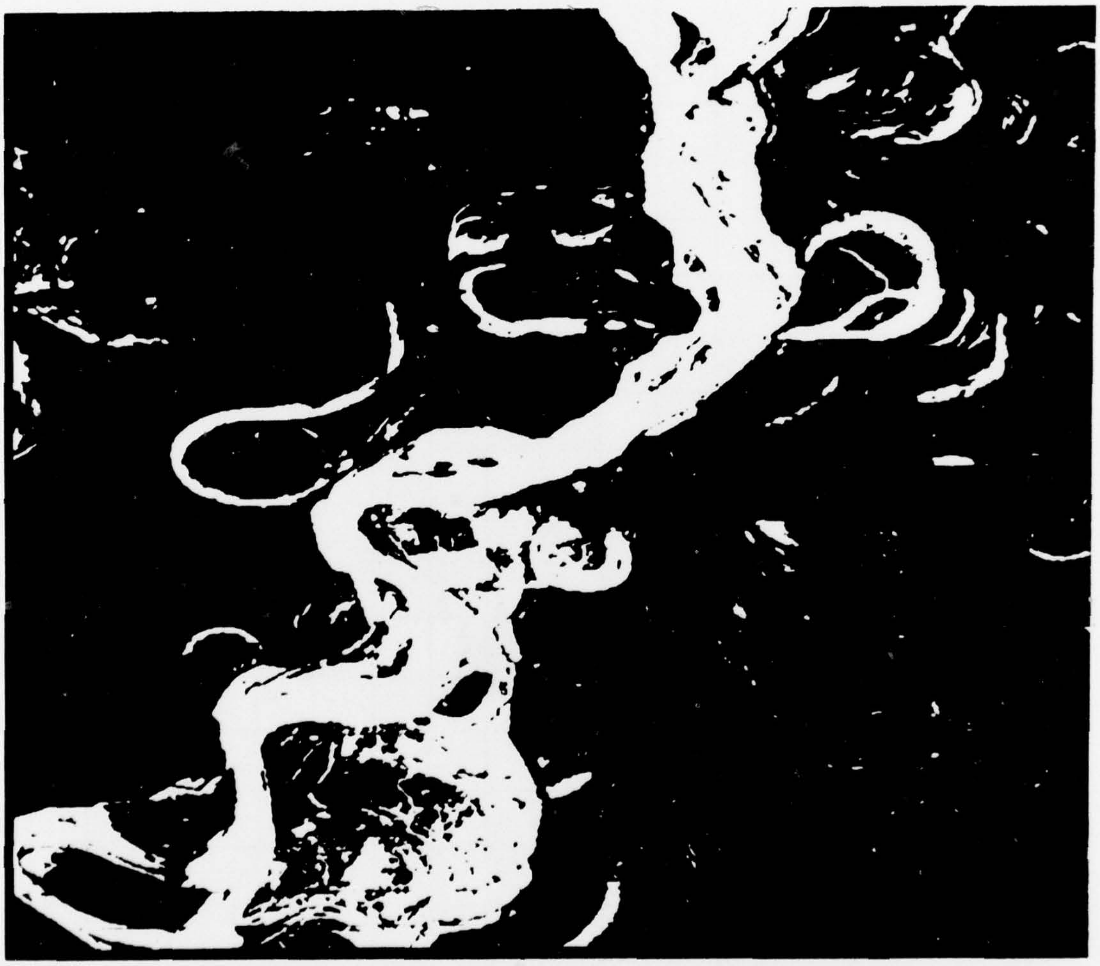


Figure C5. Sample overlay of flood in lower Mississippi River Valley

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Williamson, Albert N
Movement of suspended particles and solute concentrations with inflow and tidal action / by Albert N. Williamson. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
107, [66] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; M-78-2)
Prepared for NASA/Goddard Space Flight Center, Greenbelt, Maryland, and Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project No. 4A762719AT40, Work Unit 031.
References: p. 106-107.

1. Computer-compatible tapes. 2. Data collection systems. 3. Data processing. 4. Sediment. 5. Spectrum analysis. 6. Suspended load. I. United States. Goddard Space Flight Center, Greenbelt, Md. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; M-78-2.
TA7.W34 no.M-78-2